THE UNIVERSITY OF ALBERTA

Magnetic Survey and Archaeological Site Assessment

by

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A THESIS

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ABSTRACT

Because archaeological research is costly and time consuming a number of methods have been adopted to reconnoitre a site prior to its examination through excavation. This thesis examines one such method of reconnaissance, magnetometry. Using a proton magnetometer, thirteen historic and prehistoric sites in New England, the Canadian Prairies, Yukon Territory and the western Canadian Arctic were magnetically assayed and the data interpreted in relation to their archaeological sources. The primary goals of the research were to evaluate the the technique's applicability to various methods of archaeological research, and determine the most useful means of employing magnetic survey on various types of archaeological sites.

Because most archaeologists have limited opportunity to become proficient in interpreting magnetic data using sophisticated analysis techniques, the study concentrated on the employment of simple interpretive methods which were amenable to the identification of anomalies which are most frequently encountered when assaying archaeological sites. The elementary anomaly models were used to interpret the locations of archaeological features such as pits, fire hearths, pottery concentrations and scattered metal. To aid in data analysis, several methods of automated data manipulation were investigated, including the utilization

of computer programs to analyze and plot data for immediate interpretation. This work culminated in the development of a series of microcomputer-based statistical, filtering and plotting programs which enabled rapid analysis of magnetic data as they were acquired in the field.

Six case studies were used to illustrate the wide range of archaeological questions that can be addressed using simple magnetic survey techniques. In the process, a few of the limitations of magnetometry are illustrated and some procedures are described whereby these limitations can be minimized. The study culminates by evaluating the cost effectiveness of magnetometry in comparison to traditional site assessment techniques. The conclusion is that if magnetic survey is used in conjunction with conventional techniques of site investigation, a very powerful assessment methodology can be developed which can be effectively applied to a large number of historic and prehistoric archaeological sites in North America.

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CHAPTER I

INTRODUCTION

Archaeological research is costly and time consuming. As a result considerable thought and effort has been invested in designing and testing more efficient methods of recovering data from archaeological deposits. Because of the costs in time and labour, site excavation has stressed sampling rather than complete excavation.

When deciding an excavation sampling strategy, several different procedures can be implemented. The intuitive approach, probably the most common "sampling" method, involves concentrating excavation on site topography similar in pattern to that discovered at previously investigated sites. Another method is to establish several randomly arranged test excavations over a site and then concentrate most effort in those areas in which the tests have demostrated artifact or feature productivity. A still more sophisticated form of sampling relies upon statistical theory to obtain an unbiased site sampling strategy (eg. Mueller 1975).

Excavation on historic sites usually begins in the vicinity of sub-surface indicators (eg. anomalous topography or differential vegetation growth) which suggest the presence of buried features. If these indicators are not apparent, systematic trenching and test pitting may

succeed in intersecting important remains which can then be excavated more thoroughly.

Each of these excavation procedures will result in some non-productive excavation, because test digging will enevitably be carried out in sterile areas. For this reason alternative methods employing "prospecting" techniques have been developed. Prospecting techniques enable the archaeologist to identify areas within a site which may contain archaeological remains. Important historic and prehistoric features such as hearths, pits, walls and floors, and even artifact clusters have been located in this way without having to undertake major test excavation programs. Although few archaeologists regularly employ prospecting techniques they can significantly reduce the factor of chance in finding archaeological features and therefore reduce costs of time and labour.

Most conventional prospecting techniques used in archaeological studies have been adopted from the geophysical sciences. They commonly operate by sensing differences between the physical properties of archaeological features and the soil or debris that surrounds them. For archaeological purposes it is necessary to employ techniques which are economical and efficient under adverse field conditions. This requirement limits the types of geophysical techniques which can be realistically employed in archaeological field research.

The most common techniques used in intra-site archaeological prospecting are electrical resistivity and magnetometry. Applications of resistivity exploration in historic and prehistoric site assessments have often met with success (Linington 1970; Carr 1977). However, the resistivity technique is slower and more labour-intensive than magnetometry, and the results can be affected by climatic conditions (Hess 1967; Clark 1975: 300-304). On the other hand, magnetometry is relatively rapid and labour efficient, and is not hampered by normal meteorological conditions.

Magnetic surveying involves obtaining precise measurements of the earth's magnetic field at specific points above ground surface. Practical magnetometry was first successfully applied to archaeological testing in England in 1958 (Aitken et al. 1958) with the advent of a portable instrument sufficiently sensitive to be used to detect the relatively small magnetic effects of archaeological features. During the first half of the 1960's archaeological magnetic prospecting was actively carried out in England and mainland Europe and to a lesser degree in North America. Pioneering studies were first implemented on sites bearing structural remains such as stone floors and pottery kilns, since these features were very easy to detect with equipment available at the time (Aitken 1958:24,25; 1959a). The majority of the

instruments used were proton-precession magnetometers specifically designed for use on archaeological sites (Aitken 1959b).

Unfortunately early technical successes which stimulated the initial enthusiasm for magnetic prospecting were tempered as limitations became apparent. Because the equipment available at that time was bulky it could not be used in areas of heavy tree growth and irregular ground surface (Aitken 1959a: 34). Frequently, buried features such as walls and foundations could not be detected, particularly if they were either partially destroyed or overlying one another (ibid.). Also, instruments were prone to misleading readings caused by subsurface geology and severe magnetic disturbances induced by surface or nearby metal, and electrical power lines (Aitken 1961:83,84). These drawbacks discouraged the use of the technique since it became apparent that technical limitations allowed only the largest cultural anomalies to be discerned with reliability (ibid. 84).

These initial results, while discouraging, did not prevent some archaeologists from continuing to experiment with magnetic surveying. Although sub-surface mapping was not a realistic goal, researchers could see the advantage in locating major concealed features prior to excavation. This persistence was eventually rewarded, especially with the introduction of more sensitive and portable proton

magnetometers. Improvements in instrumentation stimulated the development of analytical procedures for interpreting magnetic data from archaeological sites. Most research embodied the development of practical techniques for obtaining magnetic data economically (Scollar 1970; Linington 1970; Clark and Haddon-Reece 1971; Clark 1975; Parrington 1979), as well as formulating procedures to interpret them successfully (Scollar 1966, 1969, 1970, 1972). However, because these improved field and laboratory techniques required the utilization of sophisticated equipment and computer software, only those archaeological projects which were oriented towards long-term research on selected sites and/or possessed uncommonly lavish budgets were able to carry on practical magnetic surveys.

At present, when most archaeologists consider the inclusion of prospection as part of their on site investigation procedure, they find that the available literature is scattered through many journals and publicatons with limited circulation. Most of what is available presents magnetic prospecting in a positive light, but spends little time explaining how the technique directly benefits archaeological interpretation or how it could be applied beyond the particular site which was investigated. Many reports dwell heavily upon the innovative use of a particular type of magnetometer, or the

sophisticated interpretation techniques used in assessing magnetic data. Other papers simply report the results of a survey, often without describing the purpose of the project, what kinds of features or objects were to be investigated, and the direct benefit the archaeologist gained from the effort expended. These reports consistently show that there is a conceptual gap between successfully employing magnetic surveying to locate archaeological features, and using the information to more effectively carry out archaeological research.

To make this link an archaeologist must know what the technique of magnetometry will and will not do in detecting archaeological features and objects. As well, he or she must know what purpose information furnished by the technique will serve in an archaeological reseach design. These two requirements give rise to the following questions:

1) what is the applicability of the technique on a particular site?

2) how much of what resources must be marshalled to carry the work out?

3) how much time will it take to produce interpreted results?

In most cases archaeologists will reflect upon these

questions and conclude:

1) I don't have time to learn how to do magnetic surveying, and I don't want to "fiddle" with it when I only have a short time at the site

2) even if I did have the time and the desire to do it, I wouldn't be able to afford the equipment or cost of hiring a consultant to do it for me

3) even if the technique worked, I wouldn't know what to do with the information anyway

It was with these typical responses in mind that the present research was initiated. Thirteen historic and prehistoric archaeological localities were investigated; seven in Western Canada, three in New England, two in the Yukon Territory, and one on the High Arctic Islands of the North West Territories. These investigations spanned environments ranging from prairie through boreal forest to tundra, and from latitudes 45 to 75 degrees north. The widespread differences in both the topographic and magnetic environments that were experienced during the fieldwork were accompanied by equally diverse archaeological problems which were formulated in a manner in which magnetic surveying could provide at least some help in finding a solution.

CHAPTER II

MAGNETIC SURVEY THEORY

AND

ARCHAEOLOGICAL FIELD PRACTICE

The Proton Magnetometer

The most commonly used instrument for measuring archaeologically related magnetic intensity is the proton magnetometer. Breiner 1973:3 and Aitken 1974:241-262 give summaries of the operating principles involved. The basic phenomenon is the precession of protons in water or hydrocarbon molecules.

Modern proton magnetometers are deceptively simple-looking instruments. A typical version consists of a metal console about the size and weight of a large textbook. A plastic container holding about a litre of sensing liquid is attached to this console by a metre long flexed cable. The liquid-filled container is the sensor, the point to which all magnetic measurements refer. The console contains the circuitry which energizes the sensor and determines the magnetic field intensity around it (a process which takes 2-3 seconds), presenting the field strength as a five digit number on an L.E.D. display on the top of the console. The number represents the absolute total field intensity in gammas at the point where the sensor was energized, with an accuracy of plus or minus one

gamma.

The Earth's Magnetic Field

In North America, the geographic field is about 0.6 gauss, or 60,000 gammas, directed downwards at an angle of about 60 degrees. Although magnetic intensity varies with location, in practical terms this spatial variation is not significant, even at the level of a single gamma, unless distances on the order of kilometres are involved between measurements. However, the field intensity fluctuates significantly with time. This fluctuation, called diurnal variation, must be closely monitored if precise measurements are required. Typically, the field intensity reaches a maximum near mid day with a gradual decrease and leveling off in intensity as evening approaches. Over a period of several hours changes of several tens of gammas may occur. Occasionally, magnetic intensity may fluctuate unpredictably by amounts in excess of 200 gammas (figure 2.1). These sudden and erratic variations are called magnetic storms. During such times, it is virtually impossible to carry out meaningful survey work.

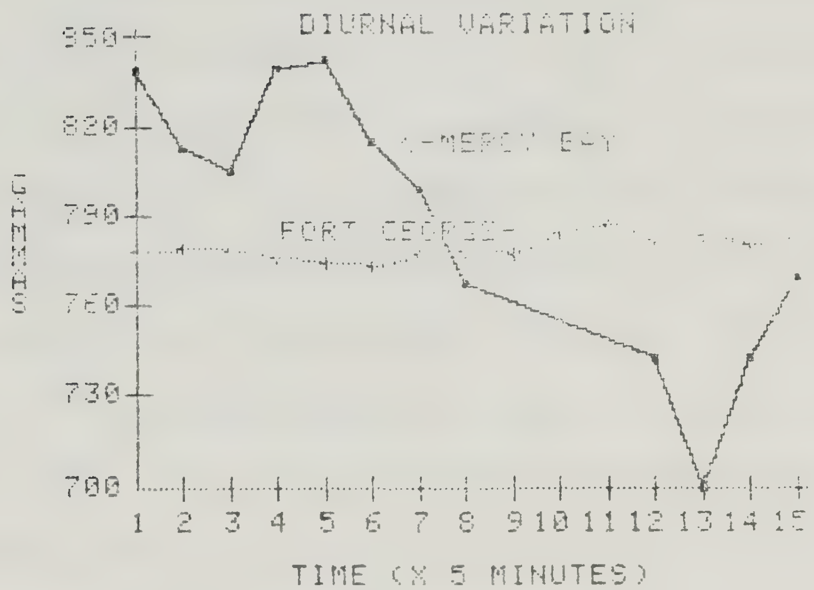


Figure 2.1 Temporal magnetic intensity variation at Mercy Bay (Banks Island), 1300-1415 hrs., July 19, 1981 and at Fort George, East Central Alberta, 1325-1440 hrs., May 31, 1979.

The Magnetization of Archaeological Features

Many objects which are encompassed and permeated by the geomagnetic field generate secondary magnetic fields of their own. These fields are the product of two different kinds of magnetism: remanence and induction. Remanent (permanent) magnetism is the inherent magnetization of an object, regardless of the magnetic field surrounding it. It is dependent upon composition and the thermal, mechanical and magnetic history of a particular specimen (Breiner 1973: 8,9; Aitken 1974: 141,142; Strangway 1970: 8-15). Permanent magnetization of an archaeological object is usually acquired by raising its temperature beyond a certain point and subsequent cooling: this is called thermo-remanent magnetization (TRM).

The other type of magnetism is called induced magnetization. Unlike TRM, induced magnetization is directly dependent upon, and proportional to, the ambient field permeating an object, to produce a secondary magnetic field (Breiner 1973: 8). The intensity of the secondary magnetic field is dependent upon the intensity of the Earth's field and the ability of the object to become magnetized, called magnetic susceptibility. If the ambient magnetic field is reduced to zero, the induced magnetization, unlike TRM, would decrease to zero.

Most archaeological features are detectable by induced

magnetization, simply because they are composed of a more sucsceptible magnetic material than the surrounding medium (Scollar 1965: 32). Induced magnetization is present in all objects which contain iron compounds. Objects composed of other substances such as copper or aluminum which lack trace amounts of iron do not produce any magnetic field.

Iron compounds contained in soil can also give rise to magnetic effects. The susceptibility of soils containing iron oxides was first investigated by Le Borgne (1955, 1960) who determined that the surface of such soils were much more magnetically susceptible than their parent sub-soils. He demonstrated that the low susceptibility of the parent material could be dramatically increased by initiating chemical reactions involving the iron oxides. The process involves chemical reduction of naturally occurring hematite to strongly ferrimagnetic maghaemite (Tite and Mullins 1971). Thus the degree of magnetic susceptibility of soil features on archaeological sites is dependent upon the amount of reducible iron oxides present in the soil, the intensity of the chemical reaction which reduced them and, in some cases, the length of time the reactions were allowed to occur (Tite and Mullins 1971: 213). Normally the intensity of the reaction or the length of time (or number of times) the reaction occurred are indeterminable prior to magnetic surveys of archaeological sites. However, the chemical constituents of a particular

site can be determined prior to a survey and used to determine if suitable quantities of iron oxides are present on the site and would have been affected by intentional burning or habitation.

Dipole and Monopole Magnetic Anomalies

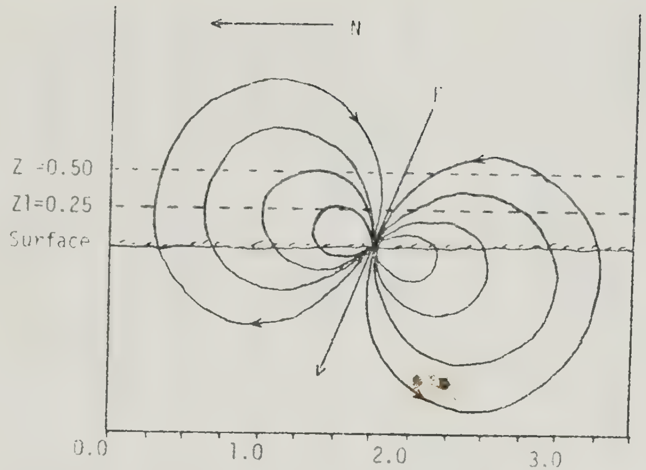
Localized magnetic anomalies are often the direct result of a number of different induced and remanent magnetizations acting in conjunction to produce a net distortion of Earth's field. However, because anomalies caused by induced magnetization are by far the most common found on archaeological sites, only these types will be addressed. For purposes of interpretation two basic models of anomaly configuration suffice. These are the dipole and the monopole.

The majority of the field research for this thesis was undertaken in areas where the magnetic field vector dips below the horizontal at angles between 60 and 70 degrees, and consequently the anomaly configurations for both dipoles and monopoles change very little with geographic location. However, at very high latitudes, where the field is almost vertical, or near the equator were the field is horizontal, significant changes in both configurations will occur. Such variations must be acknowledged prior to interpretation of magnetic data.

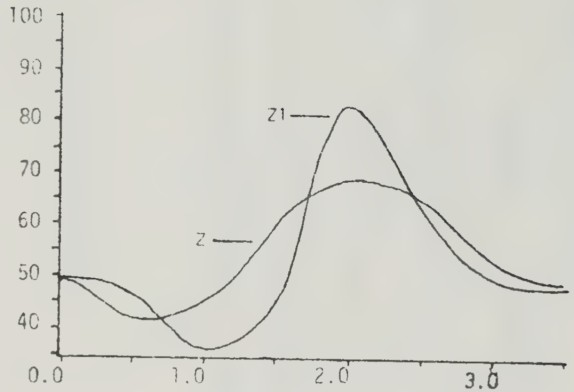
Dipole

The most common magnetic configuration of an anomaly is dipolar (see figure 2.2a). The intensity of the field is twice as large off its ends as it is at the same distance off the side. The intensity of a dipole field decreases inversely as the cube of the distance. Thus, a magnetic anomaly intensity of 8 at a distance 1 metre from an object would be reduced to only 1 at 2 metres from the object. For a monopole the the field decreases inversely as the square of the distance.

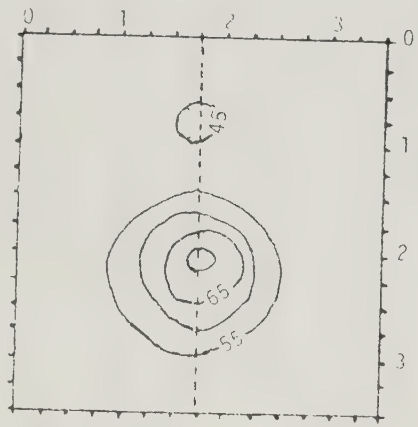
Figure 2.2a illustrates a cross sectional view of a magnetic dipole. As an example, a sequence of readings are shown with the magnetic sensor 25 cm and 50 cm above the ground surface. Figure 2.2b illustrates the resulting total field intensity measured by the magnetometer as the instrument moves through the anomalous area. The proton magnetometer always measures the total magnetic field, and this explains the profiles in figure 2.2b. For example, at 1.75 m south, the Earth's magnetic field (which, in this case is inclined at roughly 60 degrees below the horizontal) nearly parallels the magnetic field direction of the induced anomaly. The two fields are cumulative and produce a maximum as shown in the graph. At position 0.75 m south, the anomaly field direction is almost the reverse



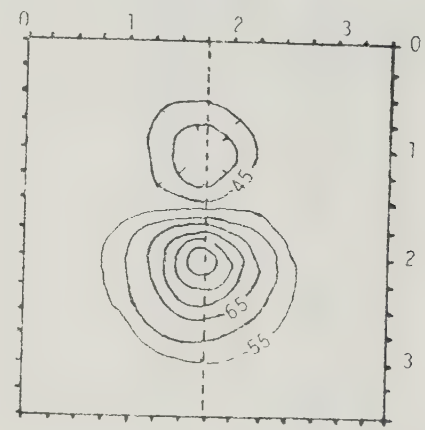
a. Idealized diagram of dipole anomaly model showing hypothetical lines of force.



b. Profile of dipole anomaly at x=1.75, y=3.5. Z=sensor up, Z1 sensor down. Magnetic intensity in gammas.



c. Contour plot of dipole anomaly. Sensor-up.



d. Contour plot of dipole anomaly. Sensor-down.

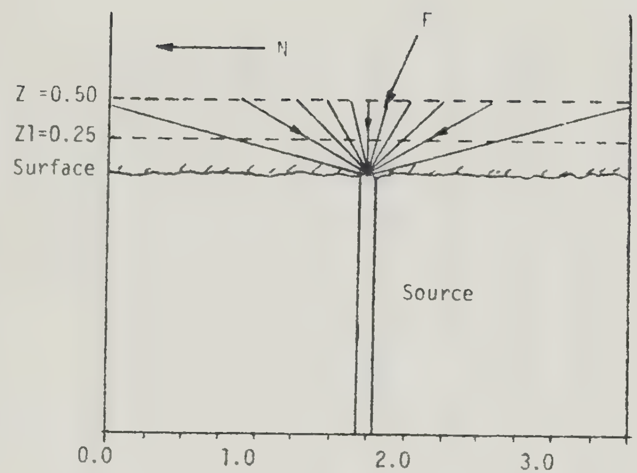
Figure 2.2. Dipole magnetic model showing idealized lines of force, single line profile and contour plots at two sensor heights.

of the ambient field. The total field is lessened in intensity, although far less than it was increased at 1.75 m south, because of the former location's greater distance from the source.

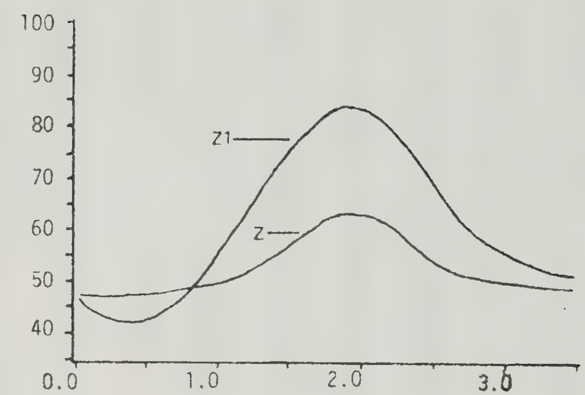
Profile graphs such as 2.2b clearly display magnetic field changes in a single dimension, but when data are obtained from a two dimensional grid it is preferable to use contour maps to display magnetic field intensity as in figures 2.2c and 2.2d.

Monopole

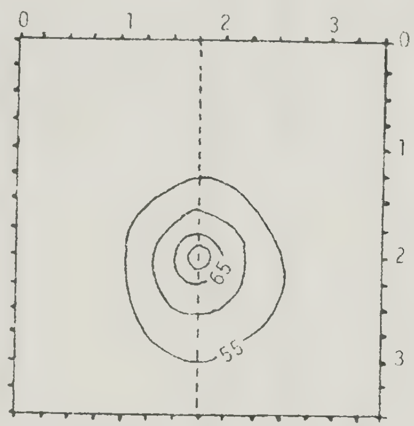
Although magnetic monopoles appear not to exist in nature, if an elongated object standing vertically in the ground is assessed by a magnetometer, the resulting anomaly will resemble that of a monopole. In figure 2.3a, magnetic lines of force are shown directed into the object from all directions. At the opposite end of the object the field lines would be directed out, but since the lower end is taken to be very deep this effect is negligible. The ambient and anomaly fields, when combined, produce a fairly symmetrical profile curve (figure 2.3b), and contour plot (figure 2.3 c and d).



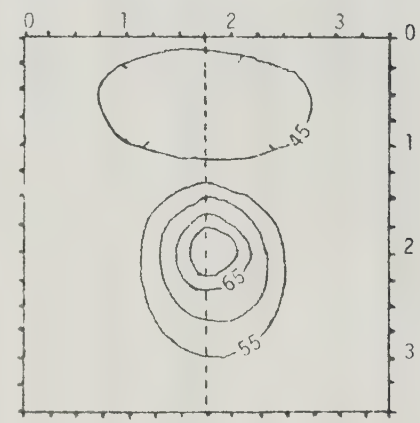
a. Idealized diagram of monopole anomaly showing hypothetical lines of force.



b. Profile of monopole anomaly at x=1.75, y=0-3.5. Z=sensor up, Z1=sensor down. Magnetic intensity in gammas.



c. Contour plot of monopole anomaly. Sensor=up.



d. Contour plot of monopole anomaly. Sensor=down.

Figure 2.3. Monopole magnetic model showing idealized lines of force, single line profile and contour plots at two sensor heights.

Gradient Measurements

Additional data can be obtained from the original upper and lower sensor readings by calculating their difference. Such data are often informally refered to as gradient measurements. Gradient measurements of this kind are independent of temporal magnetic fluctuation of more than several seconds duration. They also provide a means of removing anomalous magnetic field readings caused by deeper sub-surface features usually attributed to geology. This characteristic can be exploited to suppress broad scale horizontal magnetic trends and thereby emphasize weak anomalous magnetic fields which are often of most interest to archaeologists.

One problem in using gradient data obtained using a single sensor magnetometer is the resulting increase in machine error. This uncertainty is in the worst possible case doubled, for the experimental uncertainty of the upper reading (usually one gamma) must be added to that of the lower reading.

Magnetic Surveying of Archaeological Sites

Generally speaking, there is little procedural difference between using a proton magnetometer to locate geological formations and to locate archaeological features

and objects. The primary difference is one of scale; the archaeologist usually requires magnetic measurements at relatively close spacing (one metre or less) and with great accuracy, since most archaeological features and objects do not produce very extensive or intense magnetic anomalies. Accurate recovery of data is complicated by temporal magnetic fluctuations of the Earth's magnetic field. This problem can be overcome by comparing magnetic survey readings with those from a second magnetometer which is stationary. If a second magnetometer is not available, periodic monitoring of a designated base station with the roving instrument can be used to monitor the trend in diurnal magnetic drift, and appropriate adjustments made to the data.

The necessity of acquiring magnetic readings at close spacing presents quite a different problem which has confounded archaeologists for years. When magnetic measurements are secured from even a small archaeological site, a ponderous number of magnetic readings are usually obtained. Prior to site excavation, all these magnetic measurements must be adjusted, plotted and evaluated so that they can be used in designing an excavation strategy. If the data must be evaluated by hand, interpretation becomes the most time-consuming bottleneck in a magnetic survey program. Survey programs conducted by the author consistently demonstrated that where computer facilities

could not be conveniently accessed, manual analysis of data was severely limited, resulting in unsatisfactory interpretation.

Organizations actively engaged in archaeological magnetic surveying overcame this problem by developing automated data processing systems using computers to handle magnetic data. However, survey operations which utilize machine data processing for analysis are hampered by the substantial delay that ensues while data are shipped to a computer centre, processed, and the results returned to the field.

This methodological dilemma was largely overcome by using a portable microcomputer for data processing and automatic plotting of maps. The computer employed in this study was an Apple II plus, equipped with a disc drive for rapid data storage and a thermal printer for hard copy of maps and data. The Apple system, though designed for "indoor" operation, was easily converted for field operation using power supplied from an automotive battery. Rough handling under a variety of conditions did not affect its operation.

At the time the computer was acquired, no software had been developed for such machines to analyse and plot magnetic data. Most programs which were available for mainframe computers were not suitable for the Apple because the "single user" orientation of the latter was not

compatable with the "batch", non-interactive programs supported by mainframe systems. This was seen to be a distinct advantage offered by the microcomputer. Its highly interactive capability could be used to substantially cut down the number of data processing trials in the field, and the process of magnetic interpretation consequently made more efficient.

After a great deal of experimentation an operational software package was developed by the author for use with most of the magnetic data utilized in this thesis. The package, written in Apple II plus BASIC (APPLESOFT) consists of programs which permit raw field data to be entered by keyboard into the computer and then saved on disc as a computer file. Any stored files may be recalled and analyzed, altered through filtering, and machine plotted to produce contour maps, dot density maps or selected profiles. A more detailed description of the package of programs is presented in appendix A.

The ease of operation and very rapid speed of this series of programs permits magnetic data to be analyzed while a magnetic survey is being carried out. This flexibility permits a "feedback" relationship between data analysis and data collection which is rarely available to magnetic survey projects which rely on remote data manipulation. The practical advantage of this capability will be demonstrated in the following chapters.

CHAPTER III

MAGNETIC SURVEYING OF PREHISTORIC HUNTER/GATHERER HABITATION SITES

Although magnetic surveys have been carried out on a number of prehistoric archaeological sites, by far the majority of these investigations have been concerned with locating features such as house pits, tombs and pallisades. Prehistoric hunting and gathering campsites normally do not harbour remnants of substantial structures or excavations, and there is less reason to employ magnetic surveying techniques to assess them prior to excavation. However, such sites do characteristically harbour fire hearths, which can be relatively easily detected using a magnetometer.

Most cultural remains discovered by archaeological excavation consist of altered lithic and bone debris which was strewn about during site occupation. Excavation strategies have always stressed the ideal of sampling this debris objectively in one way or another, concentrating upon the recovery of artifacts in such a manner that they would most accurately represent the pattern of human utilization. Random sampling methods begin with the assumption that archaeological materials are non-randomly distributed about a site. Human activities, such as food preporation, tool making or social gathering usually occur

in discrete areas producing non-regular distributions of artifacts and other remains, often referred to as "contagious" distributions (Greig-Smith 1964: 61). In the course of site sampling intact archaeological features representing localized human activity are encountered; such features usually consisting of hearth remains. Because a hearth is usually the focal point of a contagious artifact distribution, excavation in the vicinity of such features will often yield archaeological materials in contexts from which a great deal of human behaviour can be inferred.

I. Experimental Models of Hearths

The magnetic characteristics of fire pits and hearths are variable, depending upon the size of the feature, the composition of the soil in which the feature sits, and the number of times the feature was fired (Tite and Mullins 1971: 216-217). Of all these variables, probably the last one is most critical for archaeological magnetic survey, for if a hearth is to be detected magnetically it must have been fired a number of times. Normal fires significantly increase magnetic susceptibility of the first few cm of underlying ground, but this layer of magnetically "enhanced" soil is rapidly diffused when mixed with unheated soils which are not magnetically susceptible (ibid.). As a result, the soil surrounding a fire must be

heated and cooled repeatedly in order to build up enough magnetically susceptible soil to generate a detectable magnetic field.

To determine exactly how a hearth anomaly would appear magnetically after different numbers of cold restarts, a limited testing program was initiated on a plot of land situated about 40 miles east of Edmonton in an Aspen Parkland environment. The experiment involved building two types of fire, a) a fire pit and b) a surface fire. Both were carried out in a magnetically calm area and repeatedly rekindled. After every firing each hearth was assessed with a magnetometer at different sensor heights.

a) For the fire pit experiment a hole 60 cm in diameter and 10 cm deep was excavated in the centre of a four m square area gridded off at half metre intervals. Before starting the first fire, magnetic measurements were obtained from sensor heights of 60 cm and 30 cm at each of the 81 grid stations. A fire was then kindled using poplar wood. The sensor wand of a thermocouple was inserted into the soil from two to four cm below the base of the fire, and at the sides of the shallow pit. During the period of burning, the instrument was monitored constantly to note maximum temperatures attained by the soil and to determine the average temperature for each burn.

Each fire was maintained for a minimum of two hours by intermittently adding wood as the fire began to diminish.

Soil temperature fluctuations appeared to be consistent for all fire pit tests. Once the burning commenced, temperatures rose very slowly to just above 250 degrees C in the first 15 minutes. Once coals began to form, the temperature again began to rise, finally levelling off at between 400 and 500 degrees C about one hour after the fire was started. Wind gusts occasionally pushed the temperature to above 700 degrees C, but only for a few minutes. Selective probings into various parts of the pit with the thermocouple wand suggested that heat did not penetrate significantly beyond three cm into surrounding soil at peak heating periods.

After two hours each fire was allowed to burn itself out and then was doused lightly with water to extinguish all coals. The pit was left for a minimum of 24 hours before it was then rekindled. In this manner, three fires were monitored. After the second fire, accumulated unburned coals were scooped out of the pit and disposed of outside the grid. After the third fire 18 light and dark quartzite rocks were placed into the pit and a fire started on top of them. Prior to this firing, the fire pit was magnetically reassessed to determine if any of the rocks were magnetic. None were found to contribute any appreciable change in the local magnetic field as compared with the previous set of readings. The rock burn was carried out in the same way as previous burns. Temperature

probes demonstrated that the rocks were exposed to temperatures fluctuating from 700 to 1250 degrees C depending upon wind gusts and the condition of the fire. After the rocks had been allowed to sit several days the grid was resurveyed and the pit filled in.

b) The surface fire experiment was carried out in the same way. Instead of excavating a hole, however, a circular area roughly 60 cm in diameter was cleared of surface vegetation. This became the hearth area. A pre-burn survey was obtained from the four m square grid surrounding the circle before firing. Temperature probes beneath the fire consistently demonstrated that heat did not penetrate as efficiently into the soil as with the fire pit. In most cases temperatures beneath the fire rarely exceeded 250 degrees C despite a large buildup of coals and rapid combustion. For the fourth burn a circle of non-magnetic rocks was established within the burned area and a fire built within and on top of them. Temperature probes indicated that though some of the rocks were occasionally subjected to temperatures above 500 degrees C most heat escaped into the open air and was not transferred to the rocks or soil.

Magnetic data from the first experiment (fire pit) were collected at least 24 hours after the termination of each burn. All data were diurnally corrected by means of base checks every 60 to 90 seconds from the northwest

corner of the experimental grid. Prior to burning, the magnetic relief of the grid was assayed, with the area of burning located approximately at its centre. Figure 3.1 displays the magnetic data as a contour map at two gamma intervals and as perpendicular profiles through the centre of the pit.

Following the predictions of Tite and Mullins (1971), as a fire is kindled, then allowed to cool, magnetically susceptible soil will accumulate, eventually in amounts sufficient to produce an anomalous magnetic field. Despite these predictions, magnetic readings retrieved from the test grid immediately after the first and second burn showed little difference in magnetic relief from those of the unburned grid. It is probable that the two burns did not produce enough susceptible material to be detected by the magnetometer. After the third firing, however the amount of magnetically susceptible soil being created during burning became sufficient to produce a detectable magnetic anomaly (figure 3.2).

The fourth firing, which included the addition of rocks in the fire pit, contributed substantially to the magnetization of the area in the vicinity of the hearth, probably because of the combined factors of enhanced soil susceptibility and thermo-remanent magnetization of a few of the rocks present during the firing. The contour and profile plots show a pronounced increase in magnetization,

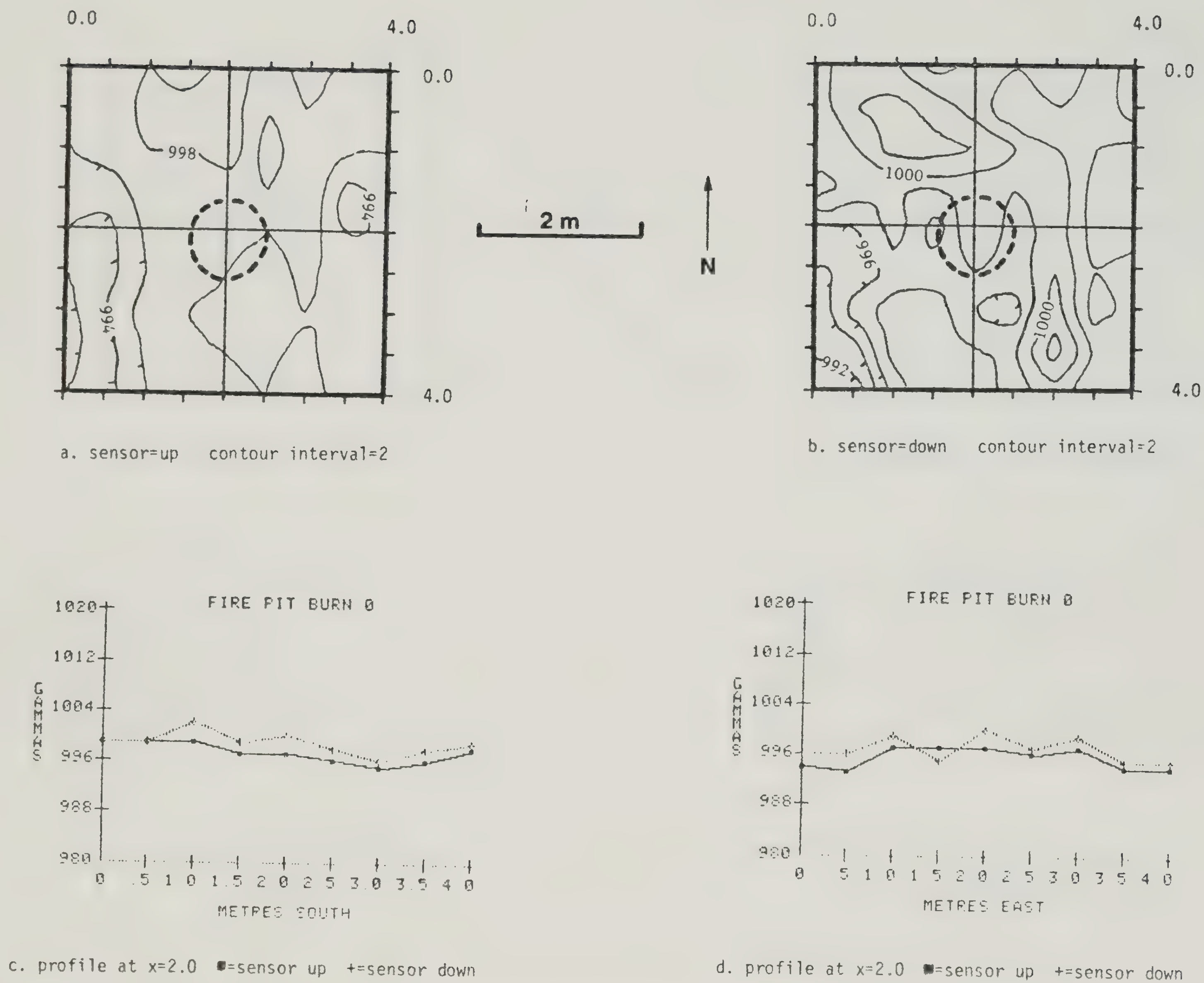
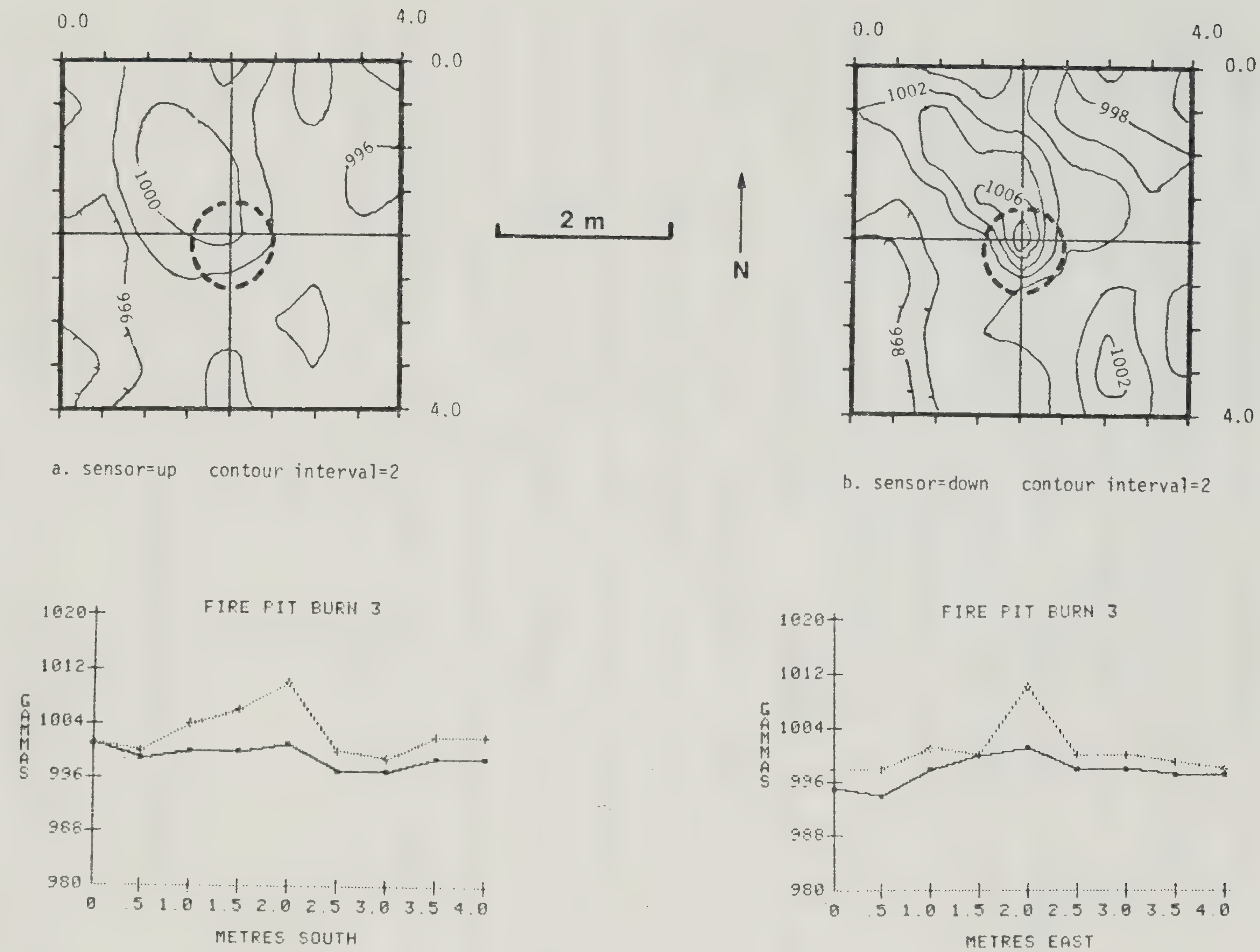


Figure 3.1 Fire pit replication experiment prior to burning, showing magnetic intensity.



a. sensor=up contour interval=2

b. sensor=down contour interval=2

c. profile at x=2.0 ■=sensor up +=sensor down

d. profile at y=2.0 ■=sensor up +=sensor down

Figure 3.2 Fire pit replication experiment, burn number three, showing magnetic intensity.

especially at the lower sensor height (figure 3.3).

The hearth replication experiments appear to substantiate Tite and Mullins' (1971) hypothesis that repeated firing does serve to increase the amount of magnetically susceptible material in a hearth. Based on this evidence it can be assumed that a fire pit which has been started a great number of times will probably produce a substantial magnetic anomaly, providing enough iron compounds are initially contained within the soil. If a great deal of susceptible material is built up in a soil horizon in a localized area, it might remain in place far longer than other soil constituents, since iron oxides are not as intimately bound into a soil's matrix as are maghaemites produced during burning. In fact, it is conceivable that if a hearth feature is subjected to intensive chemical weathering, all visible traces of its existence may be obliterated, leaving the maghaemite material as the only remnant of the hearth and its associated burning activity.

II. Locating Hearths on Archaeological Sites.

Using the data generated from the hearth replication experiment, a number of sites in six localities (see appendix B) were magnetically surveyed in an attempt to locate buried fire hearths. Three of the most significant

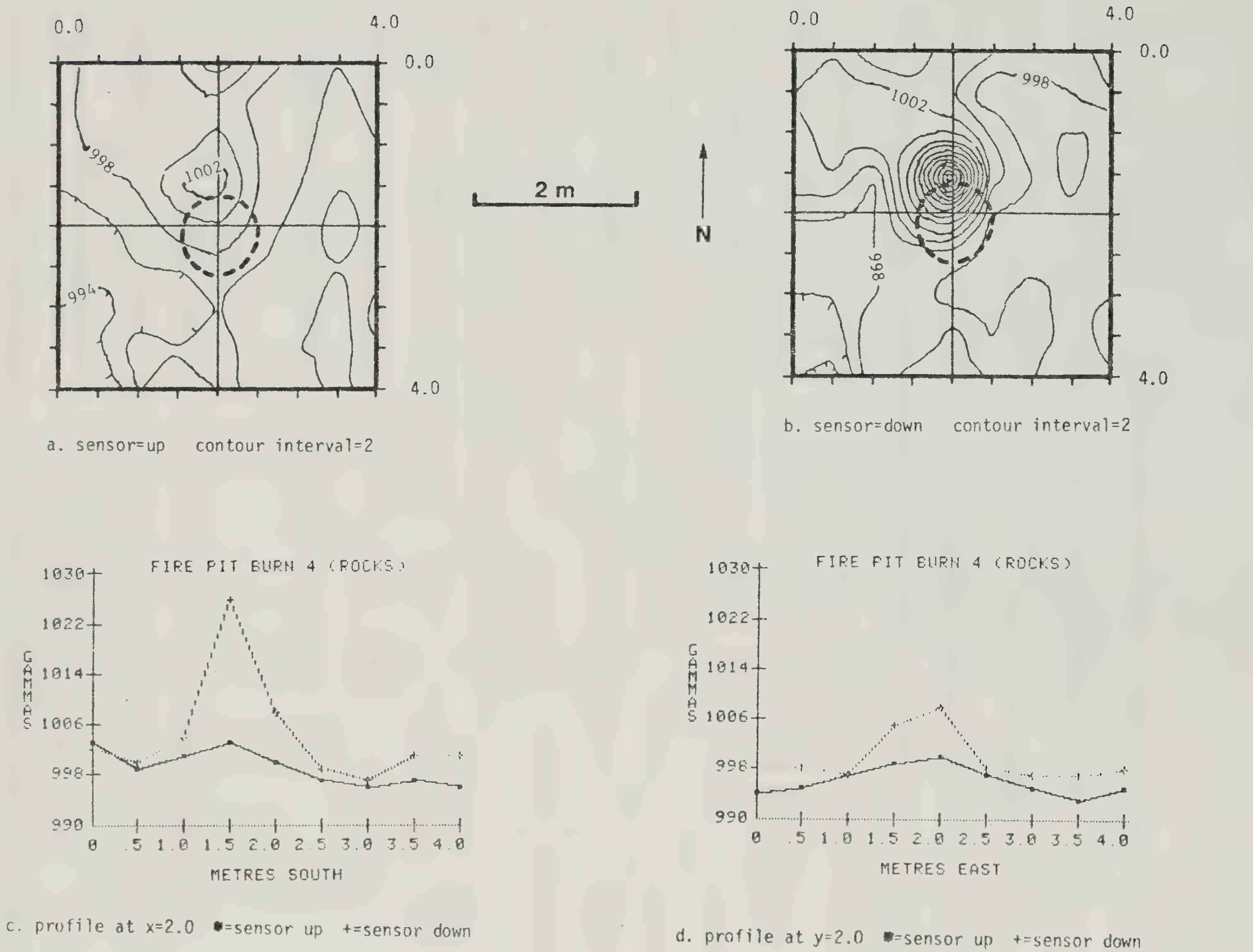


Figure 3.3 Fire pit replication experiment, burn number four (with rocks), showing magnetic intensity.

are examined in detail:

1) Caribou Island

A. Problem: The Caribou Island site is located in east central Alberta, near the town of Bonneville. Excavation of this site in 1965 revealed a multicomponent stratigraphic sequence, with the lowest occupation sitting on deposits possibly early post-glacial in age. This component was overlain by aeolian sand ranging from 80 to 130 cm in thickness. An absolute date for the lowest occupation was not obtained during excavation. Because the antiquity of the site was never satisfactorily determined a brief program of investigation was initiated in 1980 to seek more archaeological data from the lowest stratigraphic level containing evidence of human activity. One of the primary goals of this project was to locate any deeply buried hearth associated with the oldest component so that a radiocarbon sample could be obtained.

B. Methodology: An undisturbed area of the site believed to harbour evidence of human activity was gridded at metre intervals into two 20 by 30 m sections. These sections were then assayed using a magnetometer sensor height of 60 cm and 20 cm. The data were diurnally corrected by monitoring a base station every two minutes

(or more frequently, depending upon ambient magnetic activity). General survey accuracy was determined to be plus or minus three gammas. The data, once corrected, were taken to Edmonton and plotted using SURFACE II (Sampson 1978), a computer contour plotting program available from the University of Alberta Computing Services.

Two maps for each sensor height are given in figure 3.4-3.7, one contoured at 5 gamma intervals and the other at 3 gamma intervals. Using the four maps, it was possible to estimate the depth and position of most anomaly sources.

After several anomalies were located, they were magnetically re-surveyed at one-half metre intervals to determine the best area to place test excavations. The testing program that was carried out was flexible. Excavation was undertaken first in the vicinity of anomalies which suggested the presence of a fired feature buried at depth. Such a feature was predicted to produce an anomaly form similar to the dipole model explained in chapter two (figure 2.2). As excavation continued, a wider variety of anomalies were tested at lesser depths in an attempt to identify most anomaly shapes and intensities so that some direct field examples could be used for identifying most of the remaining magnetic disturbances on the site.

C. Results: Seven 1x2 m test units were excavated, and

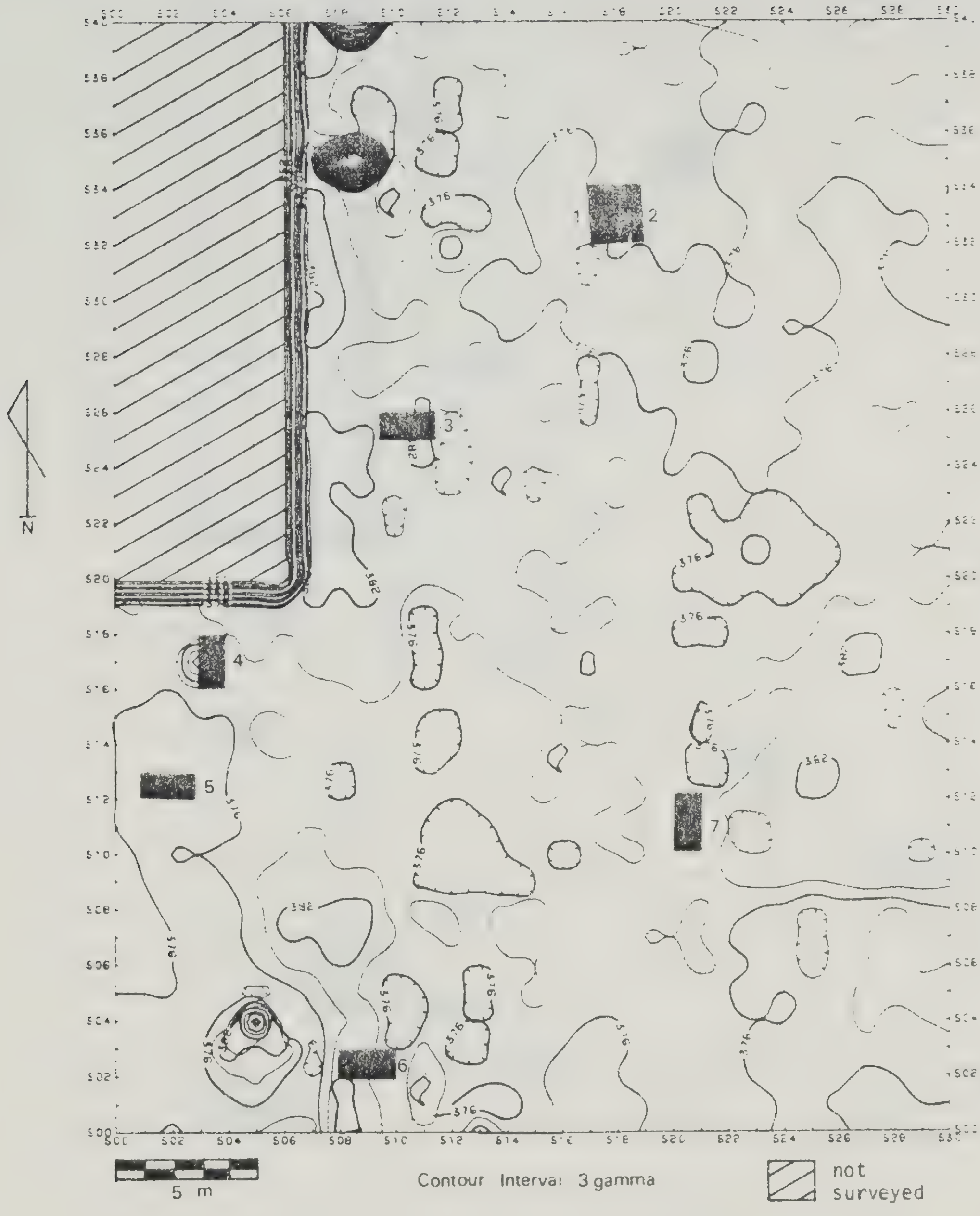


Figure 3.4 Caribou Island site magnetic intensity. Sensor=up (Z).

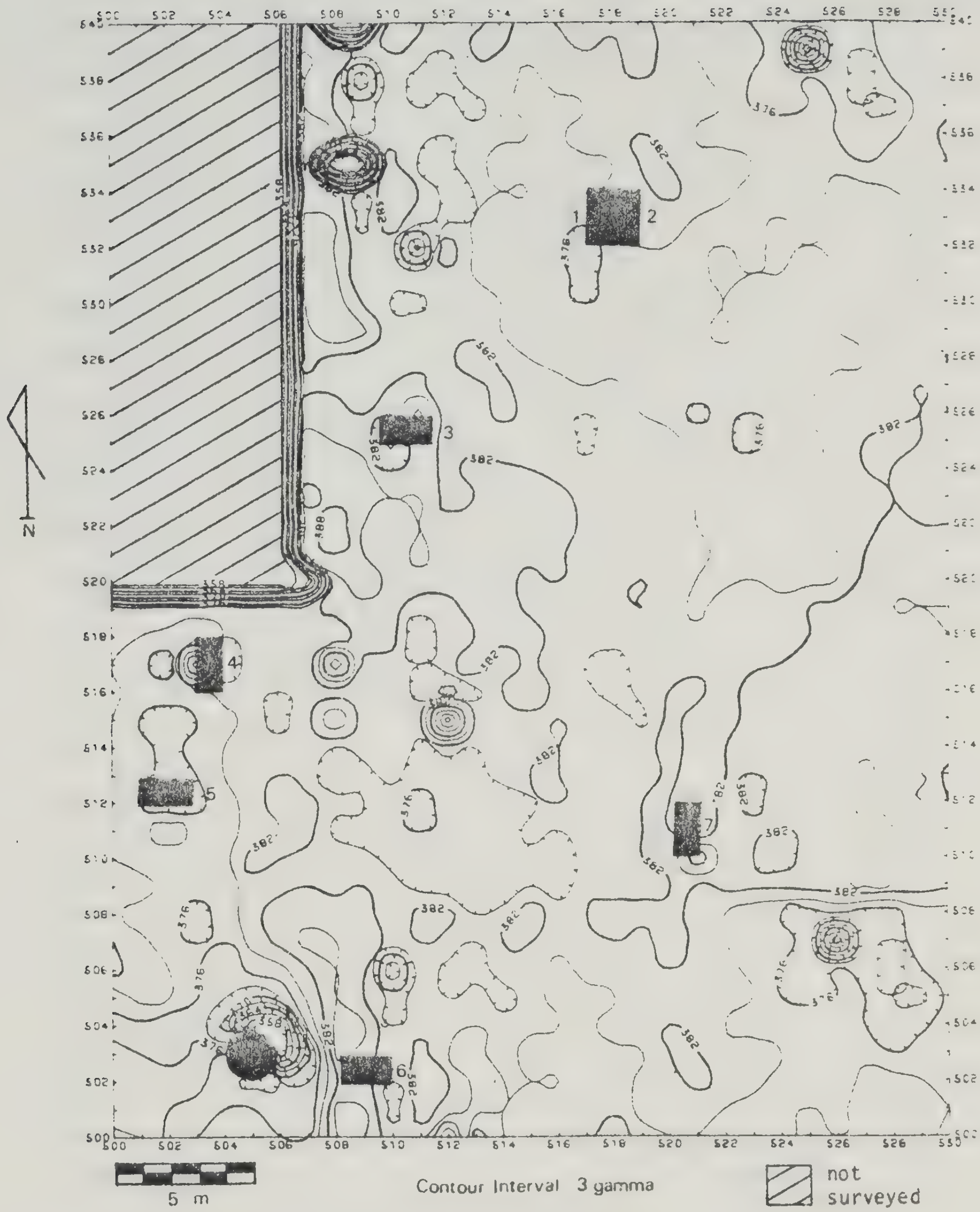


Figure 3.5 Caribou Island site magnetic intensity. Sensor=down (Z1)

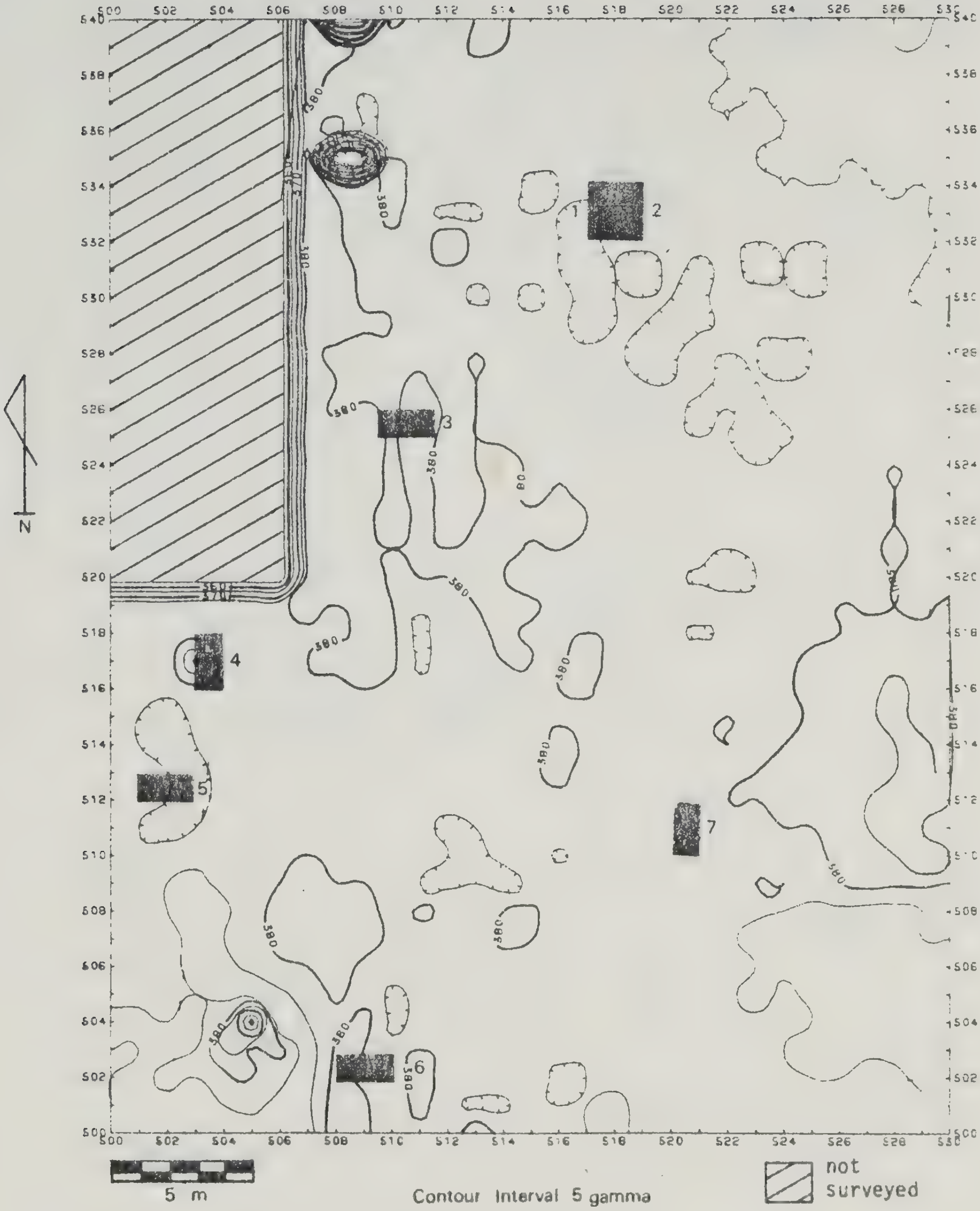


Figure 3.6 Caribou Island site magnetic intensity. Sensor=up (Z).

Figure 3.7 Caribou Island site magnetic intensity. Sensor=down (Z1).

a summary of excavation finds appears in table 3.1. All but one unit produced an identifiable magnetic source situated at the expected location and depth. The exception, unit #6, was mistakenly established in a region of poorly defined magnetic disturbance and, not unexpectedly, produced no indication of a magnetic source. Other units exposed buried metal, an old excavation unit dating from work in 1965, a deeply buried igneous boulder and a localized subsurface sand intrusion into the underlying cobble bed.

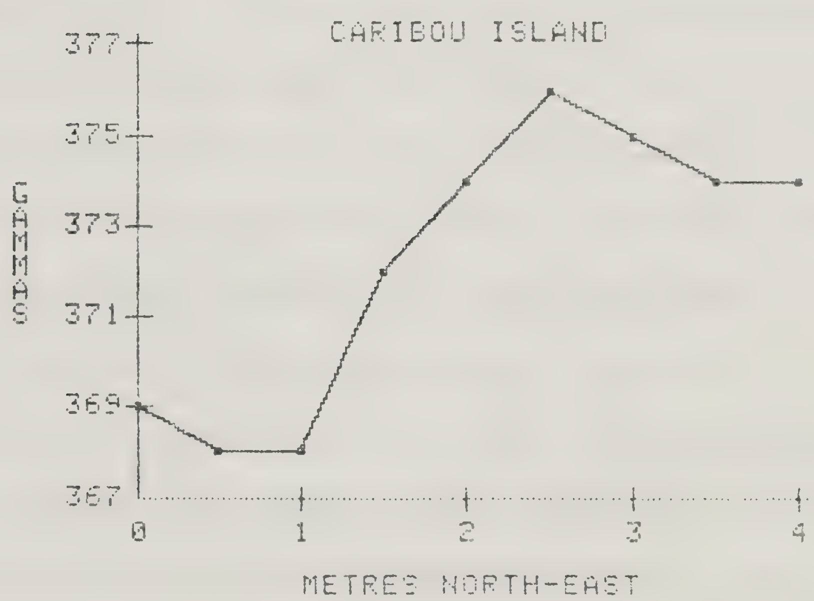
Units 1 and 2 were positioned over a deep lying anomaly source thought to most closely resemble a hearth-generated anomaly. Based on theoretical models, it was reasoned that the apparent three m separation of the anomaly maximum and minimum in figures 3.4-3.7 represented a hearth buried approximately 100 to 140 cm below the surface at 518 east, 533 north of site datum. To verify the data from this grid, a second set of readings was obtained in the area of units one and two at one half m intervals. Only upper sensor readings were obtained. The resurvey data verified the presence of an anomaly in the general area, although the exact position of the source could still not be determined (figure 3.8).

Units one and two were excavated in the area 2-4 m east, 2-4 m south and the overburden removed to a depth of 120 cm. At this point a layer of quartzite cobbles from

Unit	Provenience north	Provenience east	Depth (cm)	Anomaly Source
1	532-534	517-518	120 cm	crest of subsurface till
2	532-534	518-519	120 cm	crest of subsurface till
3	525-526	509-511	45 cm	buried igneous boulder
4	516-518	503-505	15 cm	buried tin can
5	512-513	501-503	65 cm	old backfilled excavation
6	502-503	508-510	40 cm	erroneously placed unit
7	510-512	520-521	55 cm	sand intrusion in till

Table 3.1. Results of magnetic anomaly excavation at the Caribou Island site.

a. magnetic intensity, contour interval=2



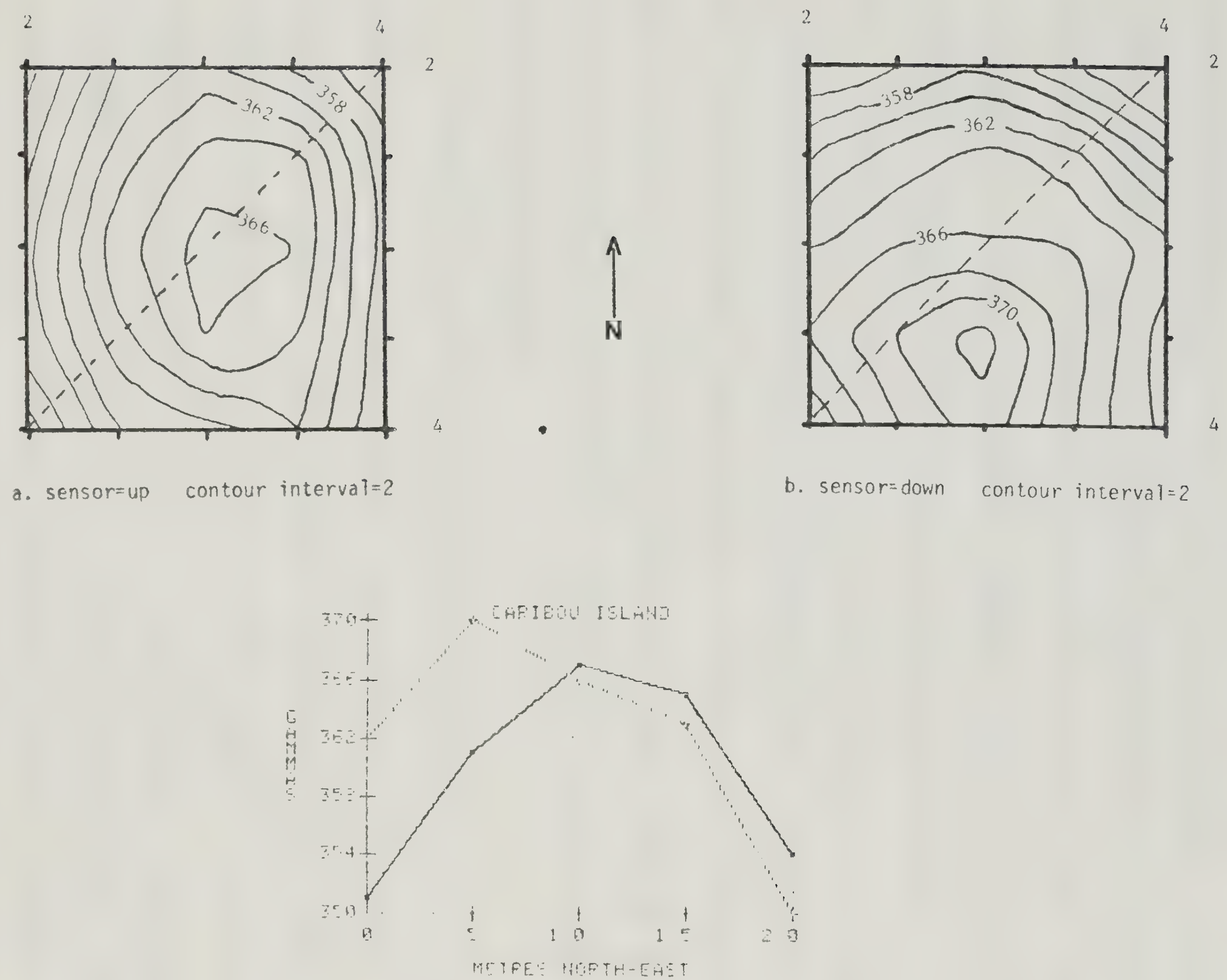
b. profile of magnetic intensity from X=1,Y=5 to X=5,Y=1.

Figure 3.8 Caribou Island site magnetic resurvey, sensor=up (Z).

the till underlying the site was exposed. It was on this surface that evidence of occupation by humans had previously been discovered and where possible hearth features were being sought. The till surface proved to be sloping, with the high point of the slope incline approaching the south half of the excavated unit. No hearth remains could be observed anywhere on the cobble floor, although a number of quartzite artifacts were recovered. After excavation, the unit was again magnetically surveyed at half m intervals. The results demonstrated a magnetic high between 3 and 3.5 m south and 3 m east, based on information from the upper and lower sensor readings (figure 3.9).

A soil sample collected from the sand matrix encasing the cobbles in this area was demonstrated under subsequent laboratory analysis to be more magnetically susceptible than the surrounding sand matrix. Although this could suggest localized burning, no other evidence of hearth remains could be found anywhere in the unit (Schnurrenberger and Gibson 1980). It was tentatively concluded that the anomaly was caused by the upsloping cobble bed rather than a localized source such as a hearth remnant.

D. Conclusion: Although important data were collected in other aspects of the 1980 Caribou Island archaeological



a. sensor=up   contour interval=2

b. sensor=down   contour interval=2

c. profile from x=2,y=4 to x=4,y=2
■=sensor up   +=sensor down

Figure 3.9 Magnetic re-survey of Caribou Island site units 1 and 2, sand overburden removed.

project, the purpose of the magnetometric program was not achieved, since no hearths were found anywhere on the site and no dateable radiocarbon material was secured. The most likely reason for this failure rests with the fact that if any intensive human activity did take place in the area investigated during the early post glacial period, the activities that were carried out at that time involved mining for lithic material rather than fire building (D. Schnurrenberger 1981, personal communication). Even if fires had been built on the cobble layer their magnetically susceptible remains would probably have been very tenuous; in all likelihood they would not have been detected given the survey accuracy, and certainly not with more than 100 cm of overlying sand separating such remains from the magnetometer sensor.

Despite the slim chance of success, some important comments can be made about the magnetic project. The research goals of the magnetic program were inherently sound; the conditions and methods used to implement the research were, however, less than ideal. To detect fired features, particularly very old features, at a depth greater than one m would require a survey sensitivity much better than the plus or minus three gammas maintained at Caribou Island. If a base station had been used to control for diurnal magnetic variation, the survey accuracy on the site may have been improved to plus or minus one or two

gammas. Unfortunately, even if this accuracy had been achieved, the resulting maps would have probably been impossible to interpret because of the magnetic uneveness of the sub-surface geology. Even at plus or minus three gammas accuracy, four of the six anomalies tested were attributed to either igneous rocks, artificial features or sub-surface geological sources.

2. Munsungun Lake

A. Problem: The Munsungun Lake locality is located in north central Maine. Research there has uncovered evidence of considerable human activity extending from the late Ceramic Period to Paleo-Indian times. In 1980 a major research program was undertaken to examine a number of questions relating to this prolonged human activity. The program included major archaeological excavation, geological interpretation and paleoenvironmental reconstruction, so that lithic procurement, settlement and subsistence patterns, and human responses to the changing environment could be documented (Bonnichsen et al 1980:2).

A major stumbling block in integrating the paleoenvironmental and geological history of the area with the archaeologically determined human activities was a lack of radiocarbon dates to link geological and paleoenvironmental events to the past human history.

Although extensive test excavations had been carried out on several sites in the locality, producing diagnostic artifacts which could be approximately dated typologically, no remains were recovered which could be used to furnish dates to correlate with pollen core sequences or geological stratigraphy. Because the soils in the Munsungun locality were extremely acidic, it was believed that the only dateable material which could reasonably be expected to survive the presumed great antiquity of some of the sites was charcoal, produced in hearths.

Because some sites were very extensive and appeared to harbour areas of intense activity in some areas and little activity in others, there was concern that traditional sampling procedures would concentrate scarce labour in areas producing few archaeological remains. This concern, when coupled with the urgent need to locate datable charcoal for correlation with results from other disciplines, prompted investigators to turn to remote sensing techniques to aid in concentrating excavation in key areas believed to harbour remains of hearths.

B. Methodology: To delineate possible areas that contained hearth remains on Munsungun Lake sites, a comprehensive magnetometer survey was initiated. In addition to this survey an equally comprehensive soil chemistry program was carried out simultaneously. This

latter project was intended to serve as a separate method of locating hearth remains by analyzing soil samples for the presence of chemicals indicating localized burning (principally magnesium, see Konrad et al 1981), and also to identify areas of charcoal concentration which might suggest intensive human occupation.

Of the four sites actually investigated by magnetometry and soils analysis, the results of the two most intensively excavated sites (154-14 and 154-7) are discussed. Site 154-14, which had yielded sample artifacts typologically dating to Paleo-Indian times, was magnetically surveyed in eight 20 m square blocks. Measurements were obtained at one metre intervals at sensor heights of 60 cm and 20 cm. Diurnal magnetic variation, controlled through repeated base referencing, proved to be minimal. Thus survey accuracy in both the single sensor and gradient mode approached plus or minus 2 gammas. Soils analysis on the same site consisted of obtaining soil samples at four metre intervals within and beyond the gridded magnetometer research area. A more detailed description of the soil survey method is described elsewhere (Konrad et al. 1981). Site 154-7, located a few metres below the terrace on which 154-14 rested, was surveyed magnetically and chemically in a manner similar to 154-14. On 154-7, two 20 x 20 m grids and one 10 x 20 m grid were assayed. Accuracy was also estimated to be about

plus or minus 2 gammas in gradient and single sensor mode. Soil samples were collect in a manner similar to 154-14.

Magnetic data were returned to Edmonton and, after adjustment, were contour mapped in three plots, showing upper, lower and gradient sensor data using SURFACE II. Because the subsurface geology produced very strong horizontal magnetic gradients on 154-14, only the gradient maps were used for interpretation at that site.

Soil samples were analyzed at the University of Maine at Orono. Soil chemical information was statistically presented as standard deviations above and below control sample means (Konrad et al. 1981: 5). The data were placed on separate site maps and later transferred to the magnetic gradient maps of 154-14 and upper and lower data maps of 154-7, for direct field interpretation.

Excavation of 154-14 was guided by the results of the magnetic data used in conjunction with soil chemical data. Magnetic anomalies which appeared to be strongly dipolar or monopolar and which lay in the general area of high soil magnesium content were overlain by small grids and re-investigated at half metre intervals. After hand mapping of these data, excavation units were established in numbers which would best reveal sources for the anomalies. Six localized areas of investigation were eventually excavated. These localities were distributed over an area covering three quarters of the western half of the site.

Only one locality was investigated on 154-7. This localized area was chosen solely on the basis of magnetics; insufficient time remained in the field season to examine other promising areas of the site which manifested abnormally high soil chemical data.

D. Results: Although the typology of the artifacts from 154-14 suggested great antiquity, deposition rates were apparently so small in the Munsungun area that the archaeological component was buried only a few cm beneath the site surface. Excavation in the region of all magnetic anomalies demonstrated that archaeological remains were concentrated primarily within the Ae horizon of the soil profile, between five to ten cm below ground surface. Thus, hearth remains were not expected to lie at any great depth.

On 154-14, this did not prove to be the case. The archaeological deposits were quickly demonstrated to be severely disturbed by many thousands of years of cryoturbation and bioturbation, as the following description of each locality shows:

Locality 1 - Based on examination of the magnetic data plotted on figure 3.10, it was believed that a fire related feature would possibly rest in the vicinity of 430 east and 518.5 south. A second survey in that area at one half m intervals roughly substantiated this prediction (figure

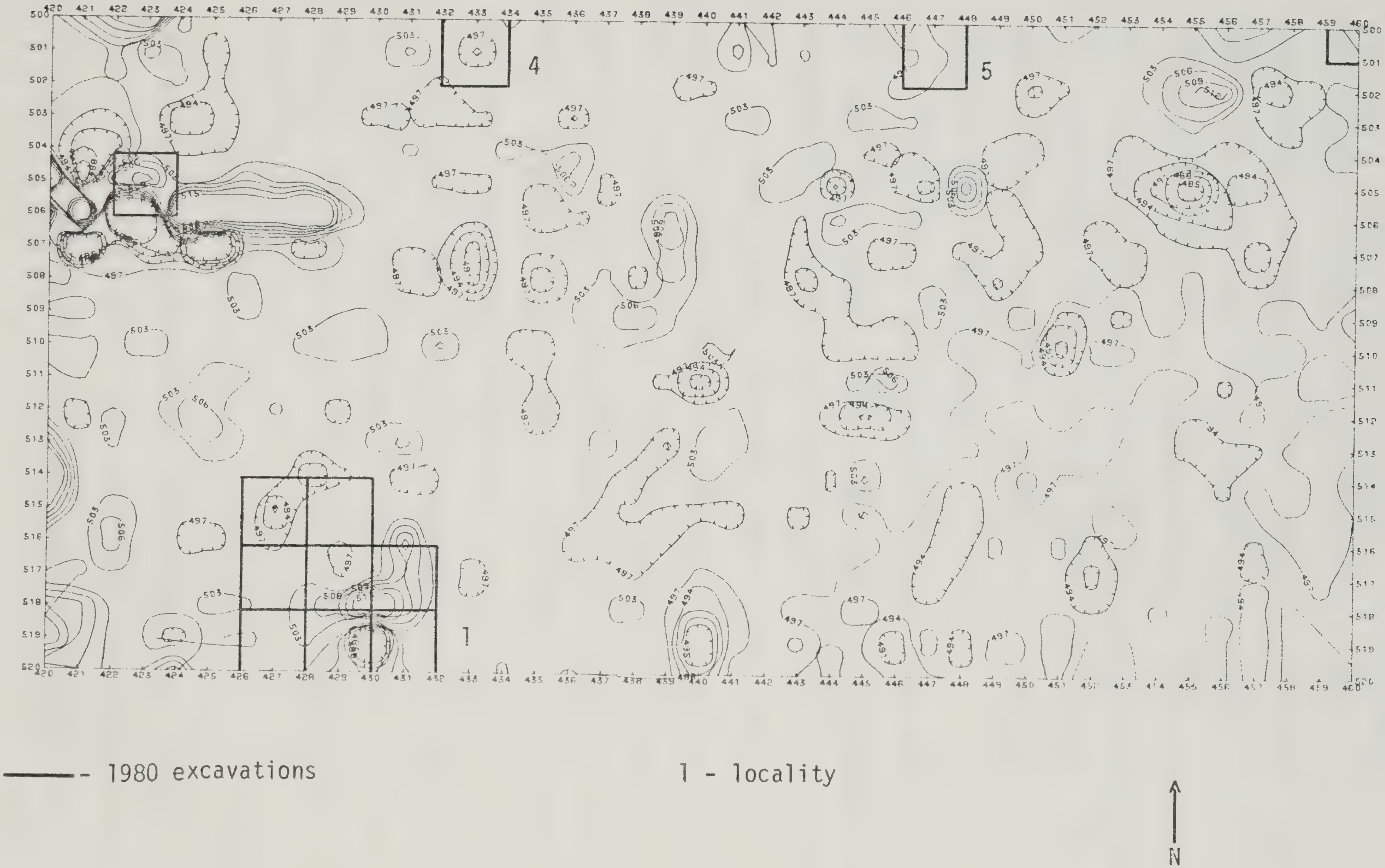
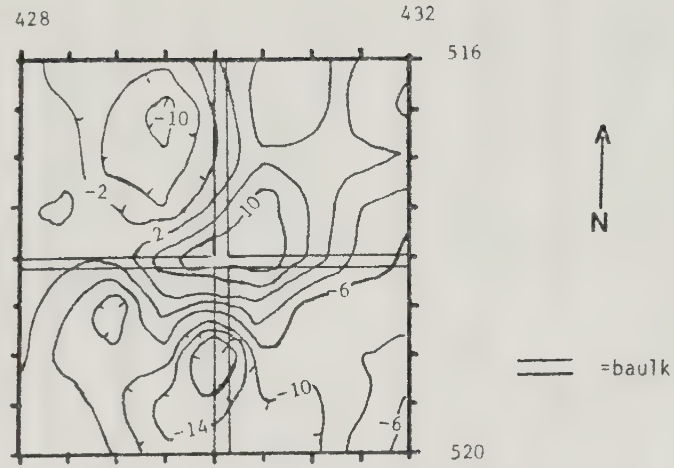


Figure 3.10 Munsungun Lake site 154-14 gradient (ZZ) magnetic intensity.

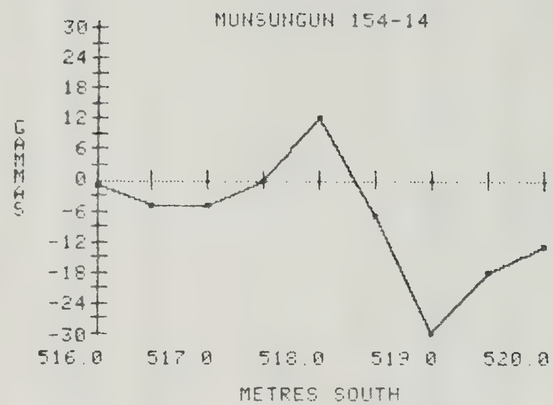
3.11 a,b). The dipolar anomaly was subsequently intersected by four two m square units. Each unit was excavated in arbitrary five cm levels after removal of the thick leaf mat, humic soil horizons and Ae horizon. Despite all four units being excavated to beyond 40 cm below ground surface, no visible traces of a hearth could be clearly discerned. A large scatter of cobbles and some charcoal was found in the Ae and upper B horizon of unit 518-520 south, 430-432 east.

After excavation, the baulks, which appeared to intersect near the centre of the anomaly, were magnetically re-surveyed by placing the sensor 20 cm below the top of each baulk and taking readings every 25 cm along their length. The survey results (figure 3.11 c,d) show that the baulks did intersect the anomaly source and retain a significant amount of highly susceptible soil because the baulk profiles indicate that the source was apparently localized in the area predicted by the survey. Unfortunately, the soil profile showed such intense natural red and orange stratigraphy (as would be expected from podzolic, iron rich soils) that no indication of any fired feature was visible.

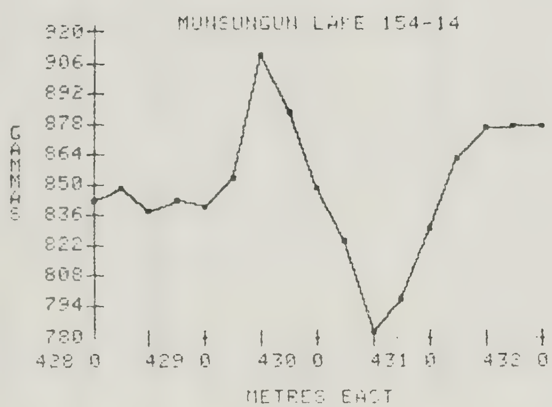
A feasible explanation that could account for the presence of the magnetically susceptible soil is that the material was the remnant of a fire pit which had been restarted a number of times. A higher than average



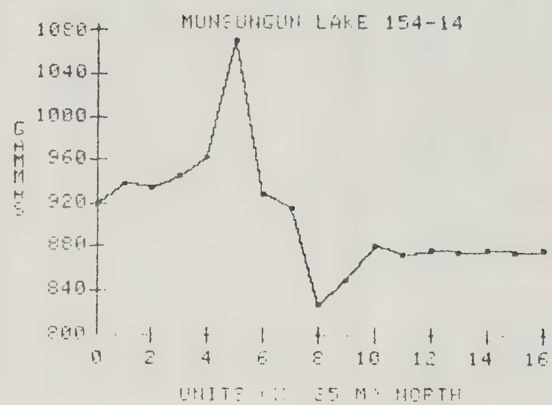
a. sensor=gradient interval=4



b. gradient profile at x=430



c. baulk survey profile at y=518



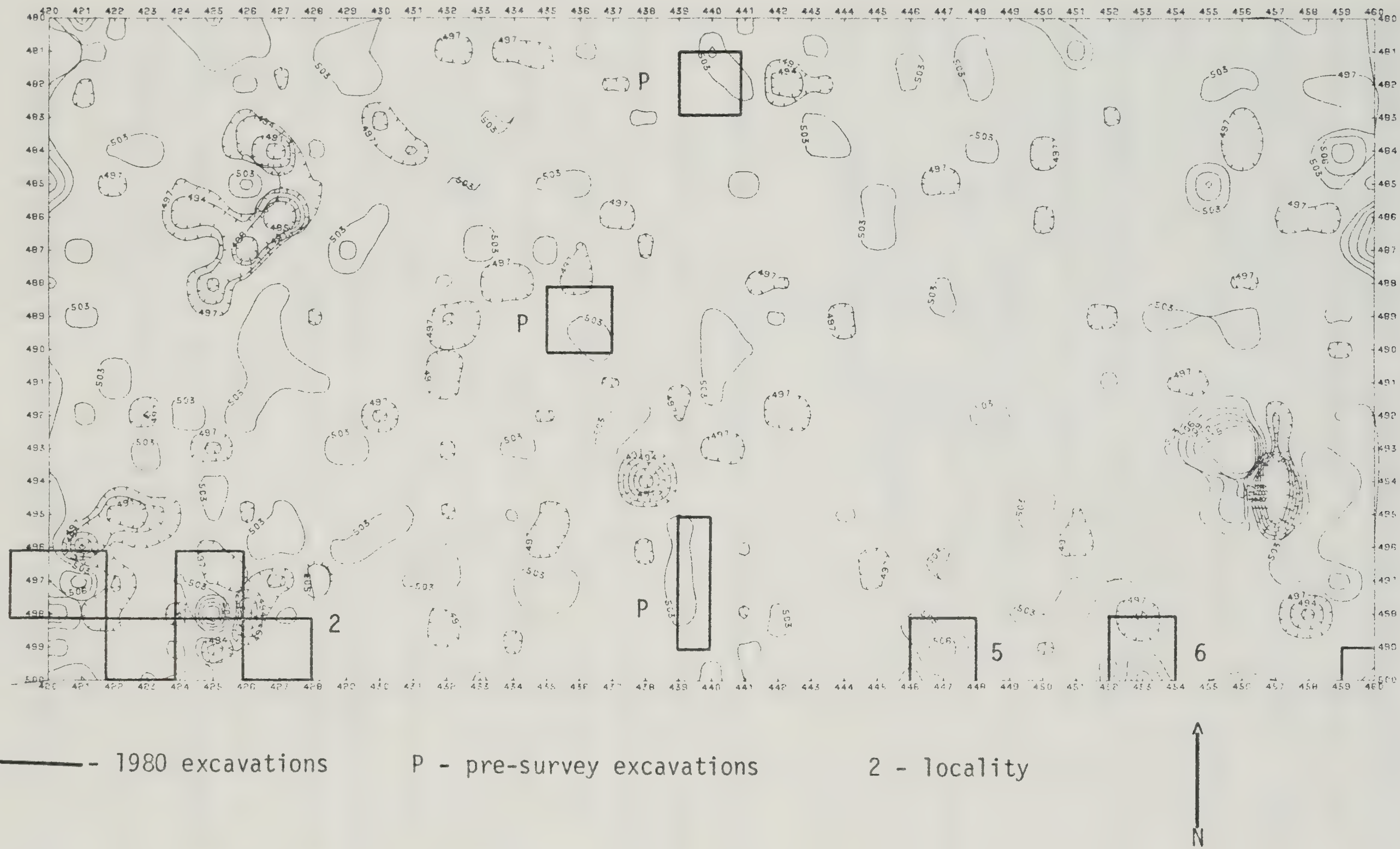
d. baulk survey profile at x=430

Figure 3.11 Munsungun Lake site 154-14 gradient and baulk magnetic resurvey of locality 1.

concentration of artifacts came from the four units surrounding the anomaly than elsewhere in 154-14. These artifacts included a number of broken and half completed lithic tools, plus several incomplete fluted points. Thus it would seem, in view of the high artifact productivity of the area, that a hearth feature may have been present in the area, but that millennia of severe weathering obliterated the visible evidence.

Locality 2- Because a number of magnetic anomalies and magnesium highs were located in a fairly localized area, intensive excavation was implemented in this area to search for possible hearth features (Bonnichsen et al. 1980: 31; figure 3.12). A checkerboard configuration of excavations was established. Few artifacts were recovered from the excavated units and extremely disturbed natural stratigraphy enabled minimal interpretation of the deposits exposed.

A depression filled with a redeposited soil horizon and intermittent buff coloured loamy soil lens containing charcoal was revealed in the area from 496-498 south, 420-422 east (ibid 1980: 32). The depression, which was partially deformed by a large boulder found intruding into it, was carefully exposed and sectioned from many directions. Its origin has not been satisfactorily determined, although it appears that the depression



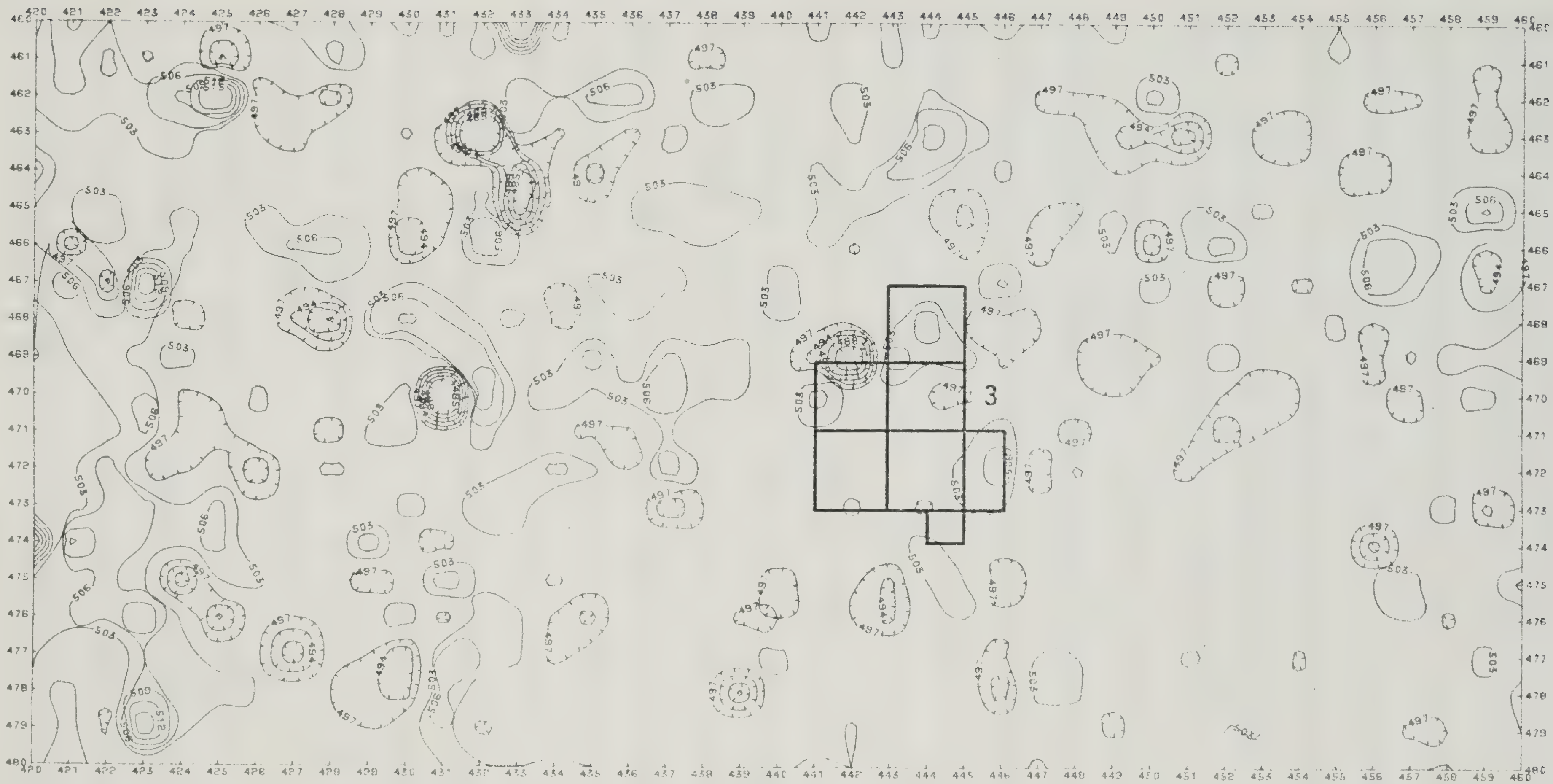
——— - 1980 excavations   P - pre-survey excavations   2 - locality

Figure 3.12 Munsungun Lake site 154-14 gradient (ZZ) magnetic intensity.

contents were at least partially derived from extensive burning (based on the presence of large amounts of charcoal), suggesting a possible hearth origin. This would account for the number of magnetic anomalies appearing within the unit. Unfortunately, the extent of stratigraphic disturbance prevented any firm conclusions being reached about the origin of the feature, and no artifacts were found in direct association with it. The anomaly at 498 south, 425 east (figure 3.12) was almost certainly caused by a buried magnetic boulder which was exposed during excavation.

Locality 3 - High magnesium readings in association with a dipolar magnetic anomaly and a number of flakes which had been exposed by a nearby tree throw prompted excavation in this area (figure 3.13). Excavation disclosed artifacts, suggesting the area was used for extensive lithic reduction, particularly to the south of the magnetic anomaly centring at 469 south, 441 east. Unfortunately, although magnetic readings suggested the presence of a highly magnetic source, no source could be detected visually. Because no intensive resurvey of the locality was carried out, it was impossible to verify the existence of the magnetic dipole.

Localities 4, 5 and 6 - These localities were not as



——— - 1980 excavations

3 - locality

N

Figure 3.13 Munsungun Lake site 154-14 gradient (ZZ) magnetic intensity.

extensively investigated because of a shortage of time available for their excavation. The units were designated because they fell along a base line intended to be excavated to determine geological stratigraphy. Thus the localities did not represent optimum magnetic anomaly or soil chemical readings for the entire site, but only for the area which was passed through by the base line.

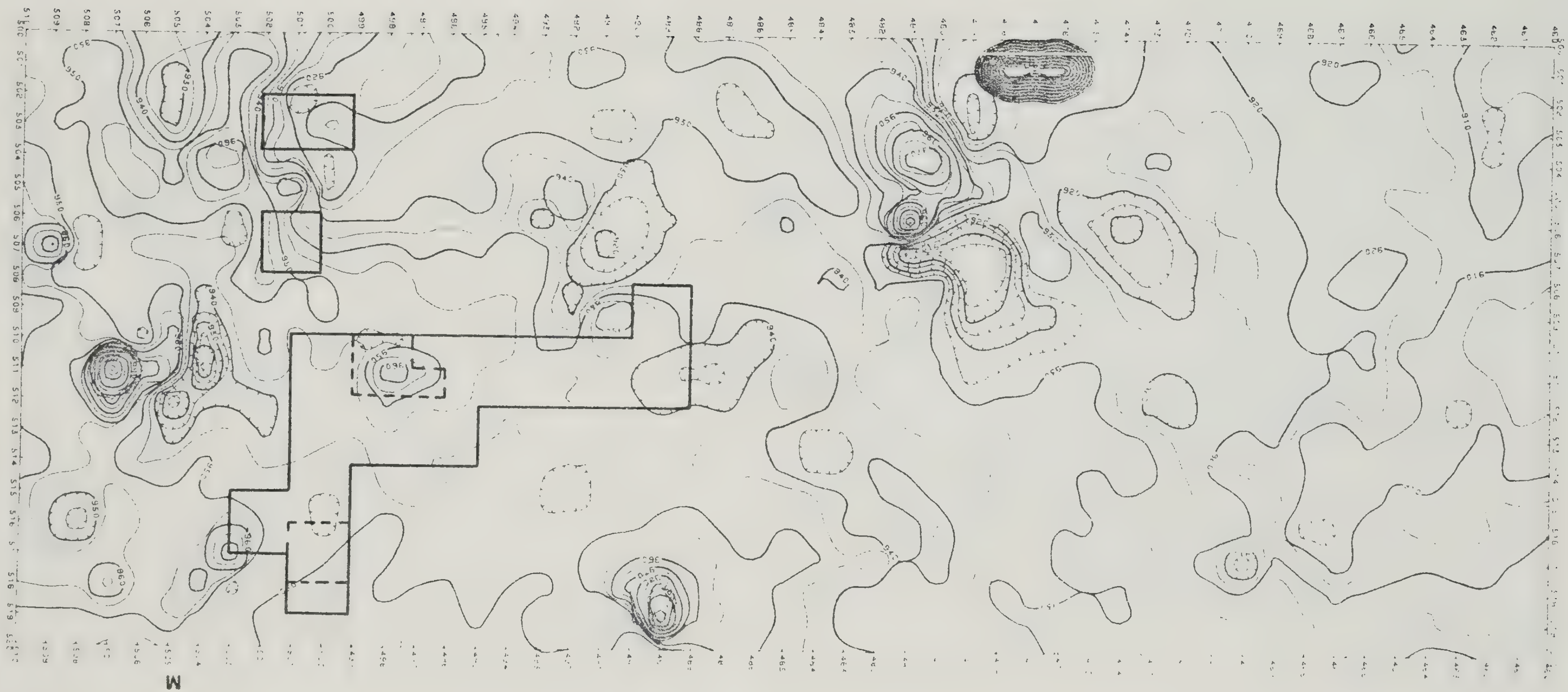
Locality 4 (figure 3.10) was not believed to be representitive of any substantial feature since it was manifested by only a small monopolar magnetic low from only one station. A magnetic resurvey was not implemented. Not surprisingly, no anomaly source was exposed, although a concentration of flakes was obtained from the unit.

Locality 5 (figure 3.10, 3.12) was magnetically re-surveyed, which confirmed the broad double monopole magnetic high on and to the north of the base line. A few possible fire cracked rocks were retrieved, but no real evidence of a fire hearth or other burning feature was visible. However, right on the anomaly high at 499 south, 447 east a vast number of lithic flakes were retrieved. The lithic concentration was up to five cm thick and displayed a radius of at least 50 cm.

Locality 6 (figure 3.12) was centred over an anomaly at 500 south, 453 east. Again, the anomaly source was not easily discernible, but appeared to be the remains of a fired feature, as it consisted of a few clustered pieces of

fire cracked rock and dispersed charcoal. Unfortunately, all remains were in uncertain context as a tree (with only the stump remaining) had grown over the rock and charcoal remains.

On site 154-7, research results were much more rewarding in the single locality excavated. The powerful dipolar anomaly centring at 498 south, 511 east proved to be caused by a substantial hearth remnant (figure 3.14, 3.15). After the feature was partially exposed it was magnetically re-surveyed at a one m interval at two sensor heights, revealing an intensive dipolar anomaly (figure 3.16). The feature consisted of a close packed "pavement" of fire cracked rock roughly ten cm thick, lying approximately 20 to 30 cm below ground surface (Bonnichsen et al 1980: 22). Much of the feature extended beyond the original two m square exploration and could not be totally isolated. A number of important cultural materials were secured from the hearth complex, including a projectile point, a large amount of charcoal and calcined bone from a number of animal species. The bones were the only ones recovered in 1980. Although no other excavations were undertaken on 154-7 that season, a surface survey of other anomalies revealed a complex of features associated with an historic cabin, in the area 500-510 south, 500-520 east. The most obvious feature in this area was the remains of a fireplace, represented by the powerful anomaly produced at



------ 1980 excavations ——— 1981 excavations

N

Figure 3.14 Munsungun Lake site 154-7 upper sensor magnetic intensity.

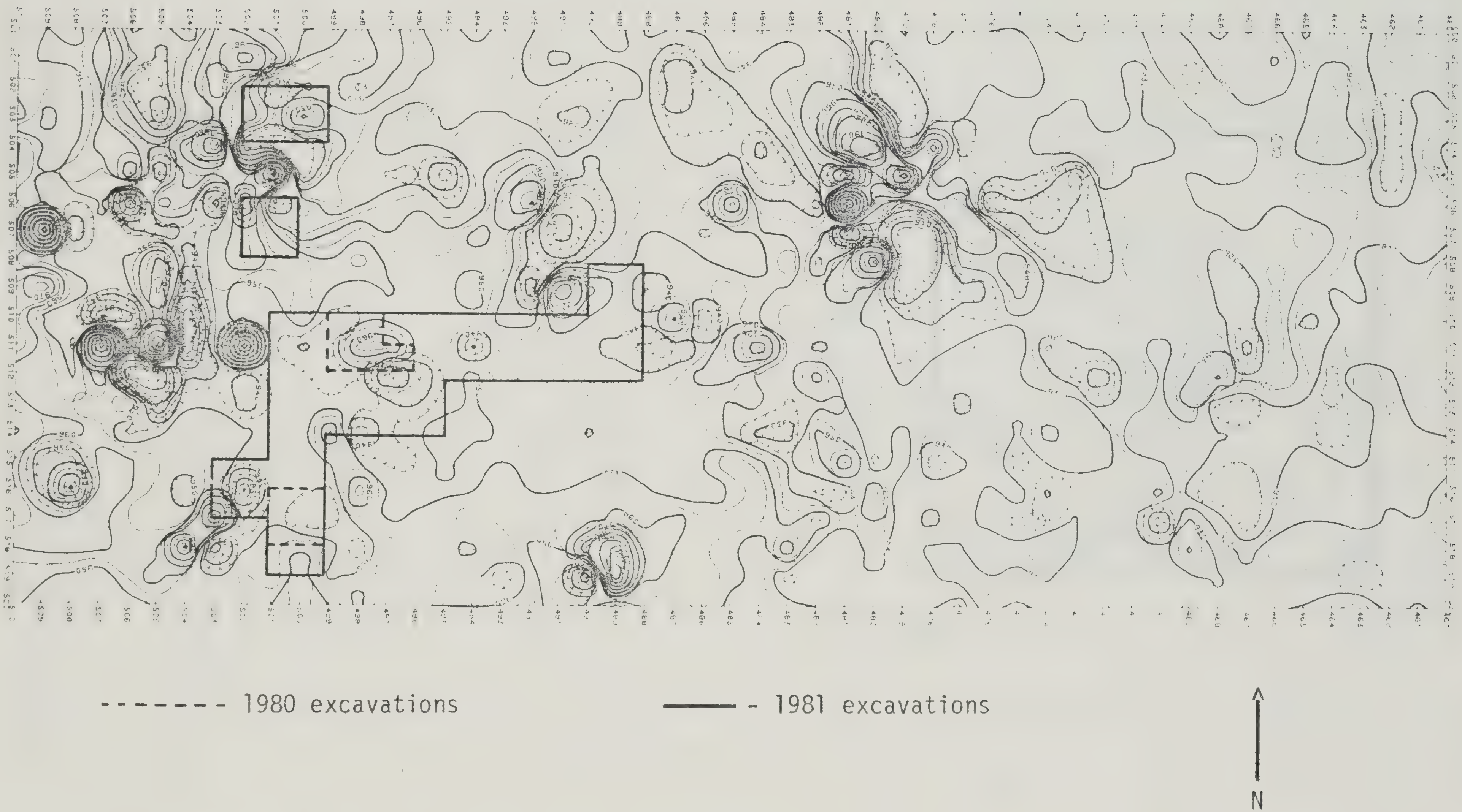
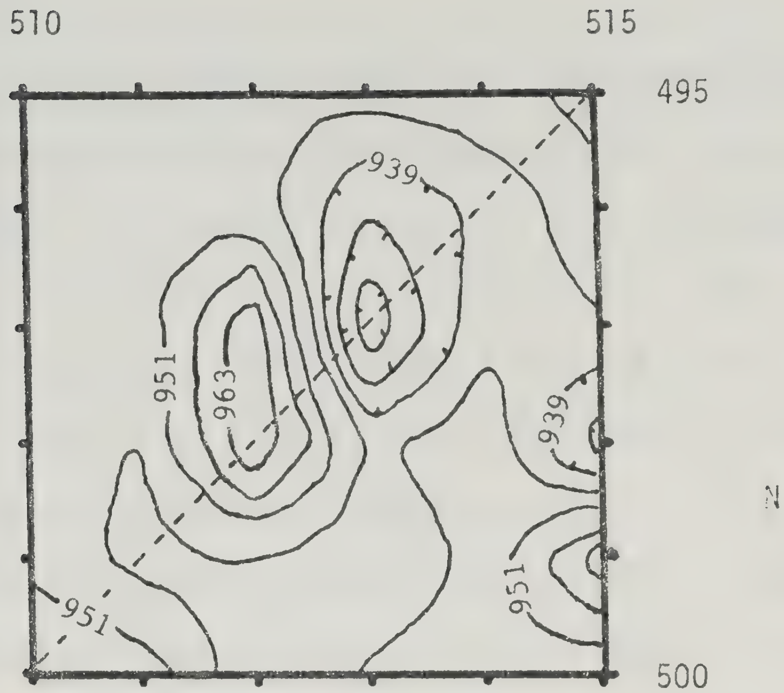
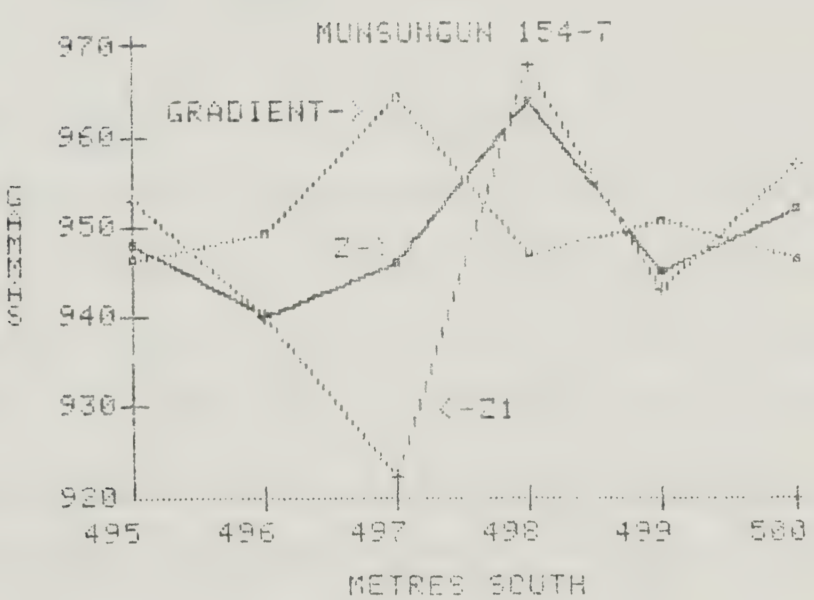


Figure 3.15 Munsungun Lake site 154-7 lower sensor magnetic intensity.



a. hearth remnant magnetic intensity. sensor=down (Z1).



b. profile of hearth remnant from x=515,y=495 to x=510,y=500.

Figure 3.16 Munsungun Lake site 154-7 magnetic intensity of hearth remnant.

506 south, 511 east.

In 1981, test excavations were continued on 154-7. These explorations did not make use of the magnetic data in choosing areas for exploration. Instead, contiguous two m wide tests were extended north and west of the 1980 units (figure 3.14, 3.15). The original hearth area was found to extend in a area 6 m square from the anomaly centre (R. Low, J. McMahon, personal communication). Trenching to the north of the hearth determined the extent of the feature but failed to encounter other hearth remains, even when a two m unit was expanded to the west of the north-trending trench. This is not surprising since this westward exploration was situated about 2 m north of the centre of a magnetic anomaly almost certainly caused by another hearth feature.

Excavations to the south and east of the original hearth fortuitously encountered a smaller hearth-like feature consisting of fire-cracked rock, calcined bone and charcoal at 502 south, 518 east. A rich lithic artifact inventory was also secured from the hearth area, including four lanceolate points. This feature exactly coincides with the magnetic anomaly shown in figure 3.14 and 3.15. Two other excavations were placed west of the original hearth. Their placement was near an area of complex magnetic relief, but not precise enough to expose the one or more sources causing the magnetic disturbances.

Therefore it is not surprising that no hearth or other feature was encountered. However, a very large bifacial core was recovered from one of the units (J. McMahon, R. Low, personal communication) which may have displayed magnetic properties sufficient to cause one of the minor magnetic disturbances in unit 499-502 south, 502-504 east.

D. Conclusion: On 154-14, the results of magnetic survey were not clear-cut, chiefly because of the extremely disturbed nature of the archaeological deposits. No archaeological features were discerned visually, other than possibly in locality two and six. The only strong magnetic suggestion of a hearth was in locality 1, where an accumulation of magnetically susceptible soil was found, traces of charcoal and rock clusters were exposed, and numerous artifacts suggesting intense human activity were collected.

The enigmatic character of this last locality brings up several points related to tactical versus strategic magnetic surveying practices. Strategic surveys involve collecting magnetic data and then leaving the site without attempting to verify magnetic anomalies by correlating them with soil samples or surface features. The data are interpreted without reference to other on-site information. This type of survey is contrasted by the tactical survey, in which interpretation is carried out as magnetic data are

collected. Resurveys, probes and test excavations are implemented on the site as required and maximum information is gathered about all important magnetic anomalies detected, and used to help interpret the magnetic data.

Had a magnetometer not been available to continually resurvey the magnetic soil concentration of locality one, the source of the anomaly almost certainly would have remained undetermined and the whole nature of the locality thrown into question. At present there is no explanation of why a localized pocket of soil should become highly magnetically susceptible except by oxidation and reduction processes resulting from intensive localized burning which removes oxygen from the soil. Based on the hearth replication experiments of this chapter, this soil "pocket" could not have been created by slow stump burning, as has been suggested, since it was concluded after the experiments (and substantiated by other researchers) that oxidation and reduction reactions were required to take place a number of times before soil could become susceptible in quantities large enough to be magnetically detectable and produce a substantial dipolar anomaly.

Excavation of some anomalies produced curious results. Locality 5, which yielded a heavy concentration of flakes but no visible hearth remains, produced a noticeable anomaly which was verified after re-survey. It is possible that a fired source may have left susceptible soil that

could not be detected. There is also the possibility that the heavy concentration of flakes may have contained materials that generated a perceptible magnetic anomaly. This does not seem probable, however, as the thousands of flakes were largely of chert which does not normally display a high magnetic susceptibility. However, the chert flakes may have been heat treated and consequently thermo-remanently magnetized. The flakes may in fact have acted in the same manner as a cluster of pot sherds, producing a net positive distortion in the Earth's ambient magnetic field which was detected by the magnetometer.

It is probable that the presumed antiquity and consequent disturbance of 154-14 contributed greatly to the extreme difficulty in detecting, excavating and interpreting archaeological remains. Diagnostic artifacts (particularly the fluted point fragments) found on the site suggest an age approaching ten thousand years B.P. Countless biological, geological and metereological incidents could have detrimentally affected the very shallowly buried 154-14 site during this very long time span.

However, diagnostic artifacts recovered from 154-7 suggest an age of less than half that of 154-14, and the condition of the cultural features supports this conclusion. Although only one archaeological test was emplaced in 1980, it was guided by evidence of hearth

remains gained by magnetic survey, and ultimately provided the most interpretable archaeological data for the whole program. The value of the remote sensing technique in this particular case was especially pertinent, for previous random testing of 154-7 had failed to intercept hearth remains, faunal material or fire-cracked rock, although many artifacts were exposed.

Excavations in 1981 continued to verify the predictive usefulness of the 154-7 magnetic data. Non-directed excavations revealed another hearth, its position predicted exactly by magnetics. Significantly, areas which did not yield evidence of burning activity also displayed no magnetic anomalies and in at least one case an exploratory test missed a magnetic anomaly (probably a hearth remnant) by several metres, exposing deposits which were relatively sterile of artifacts (R. Low, J. McMahon, personal communication).

Based on the currently tested anomalies found on 154-7, there remain a number of fruitful areas for excavation, if hearths are desired. Particulary important areas lie within three metres of 491 south, 508 east, and at 489 south, 519 east (figure 3.14, 3.15). Another extremely complex anomaly cluster is centred at 480 south, 505 east, extending in a six m radius. Unfortunately, with the data currently available, it is virtually impossible to determine exactly where these specific anomalies lie and

what their nature could be. There are at least ten other very promising anomalies that can be tested outside of the historic complex on the south end of the site.

3. Dickey-Lincoln

A. Problem: The Dickey-Lincoln locality is situated in north-central Maine, not far from the Quebec border. Survey work in the area, as part of an impact study initiated by the U.S. Army Corps of Engineers, located several archaelogical sites on landforms which could have been occupied by humans at a very early time. The sites, because of their possible antiquity, required intensive investigation to determine their elegibility for nomination to the United States National Register of Historic Places (Nicholas et al 1981: 80). Because of limited resources available for conducting this testing operation, a magnetometer survey was implemented on two sites using the same research design that was set out for the Munsungun Lake locality: to locate fire hearths as a means of isolating cultural activity loci, and to obtain hearth charcoal for radiocarbon dating.

B. Methodology: Due to a shortage of time, the research methods used were entirely strategic. Magnetic data were obtained at metre intervals using two sensor

measurements per station. Diurnal variation was controlled by base checks; survey accuacy was determined to be plus or minus two gammas. After data were collected, they were taken to Edmonton and adjusted and mapped using SURFACE II.

Because the data were interpreted off the site, no magnetic anomalies could be verified magnetically and no exploratory probes made to cross-check the magnetic data with actual site stratigraphy. Furthermore, individuals experienced in interpreting magnetic data from maps generated by SURFACE II would not be available for consultation when the sites were to be re-visited for test excavation. As a result the maps that were produced were evaluated by the author in Edmonton, using a priority system based upon example anomalies found and excavated at Munsungun Lake, a locality which displayed a geographical and geological setting similar to that of Dickey-Lincoln.

The priority system was established using anomaly configuration, intensity and size criteria, as they were displayed using upper, lower and gradient mode data. These criteria were then used to rate an anomaly in two ways:

i) absolute probability rating - This rating was based on a four point scale. Anomalies were subjectively compared to Munsungun data and a probability scale of 1=excellent, 2=good, 3=fair and 4=poor established for the probability of a specific anomaly being caused by a fire-related feature.

ii) relative probability rating - This subjective rating was applied only within a single interpretive grid. The total number of anomalies within a grid were tallied and their provenience determined. The anomalies were then rated among themselves, with the most likely hearth anomalies rating at the top (1=highest possibility) and the least likely rating at the bottom.

C. Results: As an example, the results of two contiguous test grids from site 170-1 at Dickey-Lincoln are presented in table 3.2, refering to figure 3.17. The stratigraphy of 170-1 proved to be as difficult to interpret as that of Munsungun site 154-14, with the Ah and B horizons often mixed and frequently discontinuous in nature (Nicholas et al. 1981: 91). Thus, no evidence of cultural horizons could be discerned, and archaeological features were not found intact. Despite this limitation, evidence of former features could be discerned, mostly in the form of fire-cracked rock clusters.

Because anomaly centres could only be estimated within plus or minus one metre, probing may not have been as useful in discerning sources as would have been the case with more extensive excavation. Since no secondary surveying could be carried out, the survey results were not expected to be much more accurate than presented above. However, though positional accuracy was reduced, the

Anom.	Absolute (Relative)	Test Area south	east	Test type	Test find
Grid <A>					
A	9 (3)	102-04	101-03	Test	FCR
B	8 (3)	104-05	101-02	Probe	FCR
C	5 (3)	108-10	101-03	Probe	FCR
D	1 (1)	101-03	104-06	Probe/Test	FCR
E	3 (2)	102-04	108-10	Probe/Test	FCR
F	2 (2)	106-08	107-09	Probe/test	CHR
G	6 (3)	108-10	108-10	Probe	---
H	10 (4)	106-08	111-13	Probe	---
I	4 (2)	106-08	115-17	Probe	---
J	7 (3)	102-40	114-16	Probe	---
Grid <B>					
A	2 (2)	105-07	121-23	Probe	FCR
B	3 (2)	102-04	123-25	Probe	FCR
C	4 (3)	100-02	128-30	Test	FCR
D	1 (2)	103-05	127-29	Probe	---
E	5 (4)	109-10	124-26	Probe	---

KEY

9=relative probability rating
(3)=absolute probabiliy rating
Test=test pit
Probe=soil core

FCR=fire cracked rock
CHR=charcoal
---=no source found

Table 3.2. Results of magnetic anomaly investigation at Dickey-Lincoln site 170-1.

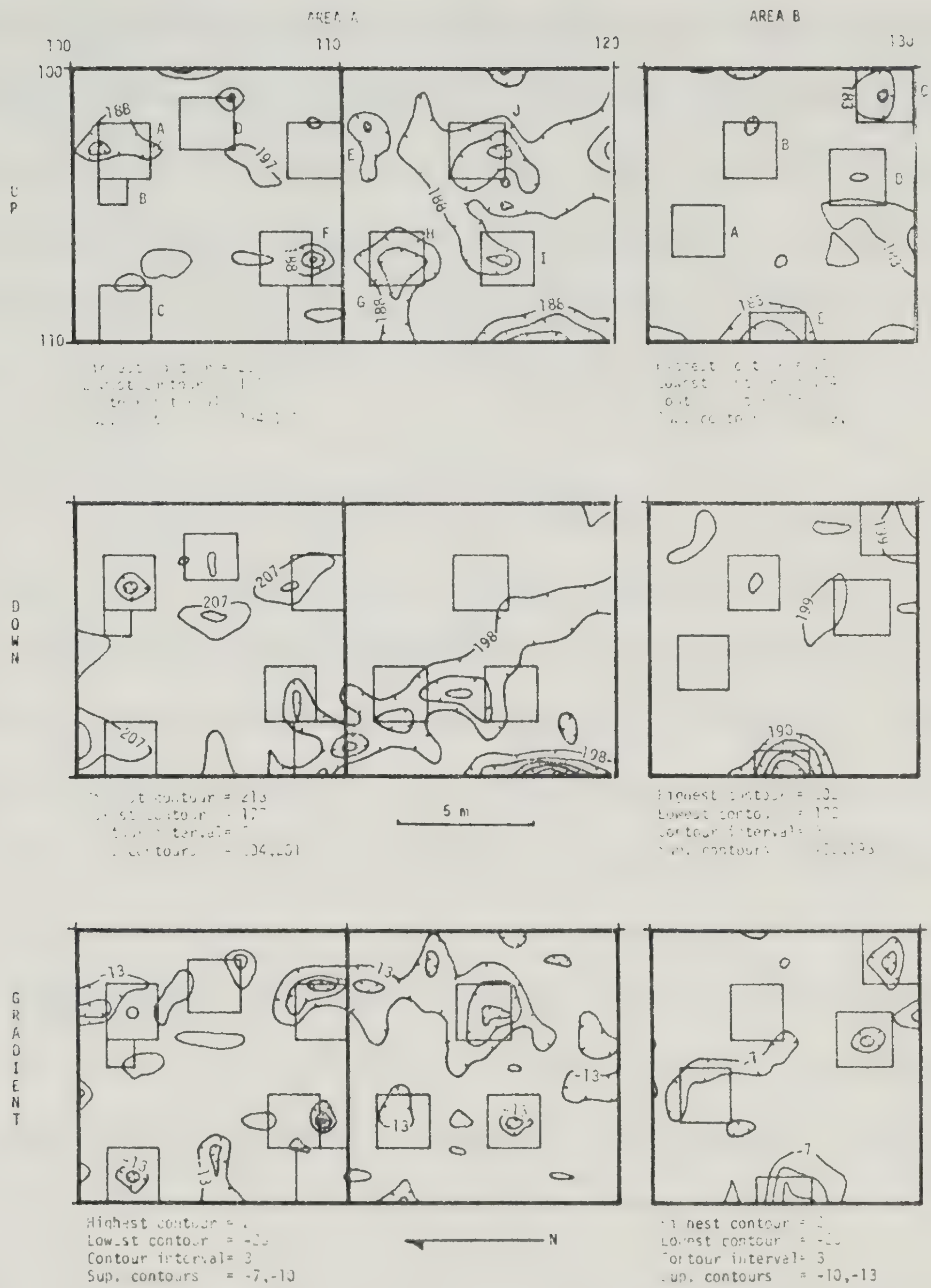


Figure 3.17 Dickey-Lincoln site 170-1 magnetic intensity, Area A and Area B.

researchers who subsequently tested the site reported a success rate of over 66 per cent using the tables in correlating anomalies with cultural remains (ibid.: 91). They further acknowledged that the success ratio would have been improved had the survey been more exhaustive in magnetically verifying local subsurface anomalies prior to excavation so that natural anomalies could have been weeded out.

D. Conclusion: The successful results of the magnetic survey at Dickey-Lincoln can largely be attributed to the special research methodology used in applying the magnetic data to an archaeological testing program. Using the probability tables and rapid testing procedures, major areas of prehistoric activity could be approximately located and excavation accordingly initiated. The computerized data processing did entail a substantial delay (over a week) before excavations could be instituted, primarily because the mapping system used was available only at the University of Alberta. Had the microcomputer-based processing system eventually developed been operational for this project, it is probable that the survey results would have been more accurate, more area could have been magnetically assayed, and excavations started much sooner.

Figure 3.17 shows a set of traced diagrams based on

the microcomputer plots of some of the Dickey-Lincoln data originally interpreted from calcomp plots produced by SURFACE II. The latter program, though fairly accurate and fast, is nevertheless somewhat inflexible because of its "batch run" orientation. As a result it is impossible to interact with it to establish specific contour intervals, suppress certain contours or produce statistical information from parts of a grid without having to re-run an entire plot. With the Dickey-Lincoln data, these shortcomings severely limited the number of plots which could be produced to closely discern archaeological features. Consequently, several of the test areas which were identified from the calcomp maps were, upon re-processing using the microcomputer software, either relocated more accurately or given a different priority. This reprocessing explains why some of the designated exploration units shown in figure 3.17 are not placed directly over anomalies, or do not contain anomalies.

III. Magnetic Search for Pottery

Prehistoric pottery is magnetically detectible through thermo-remanent magnetization. Pots and other ceramic items of fired clay often produce very significant magnetic anomalies on prehistoric sites. Unfortunately, pots are rarely recovered whole on such sites in North America; if a

vessel has been broken and the fragments scattered into a diffuse cluster, the anomaly generated by the resulting distribution may bear no resemblance to the original anomaly produced by the intact object. To determine what kind of anomaly configuration, if any, would be produced by broken pottery on archaeological sites and if magnetic survey is a feasible means of locating such materials, a program of magnetic search was undertaken on a prehistoric pottery bearing site at Child's Lake in west central Manitoba.

Although a number of areas on the site were investigated, one particular example demonstrated the magnetic characteristics of pottery fragments. The freshly exposed fragments, primarily body sherds lying flat on the ground surrounded by tree roots, were broken unevenly over a circular area 40 cm in diameter at approximately 113 m east, 119 m south of datum (figure 3.18). Contour plots of the upper and lower data revealed a broad area of low magnetic intensity over the general area of the sherd scatter, but this magnetic relief was largely obscured by adjacent strong anomalies. Profiles from the upper and lower data running south and east and passing directly over the pottery scatter did not clearly isolate the presence of the ceramic concentration from surrounding magnetic relief in the grid. Fortunately, the gradient data removed most of the horizontal gradient produced by the unknown but more

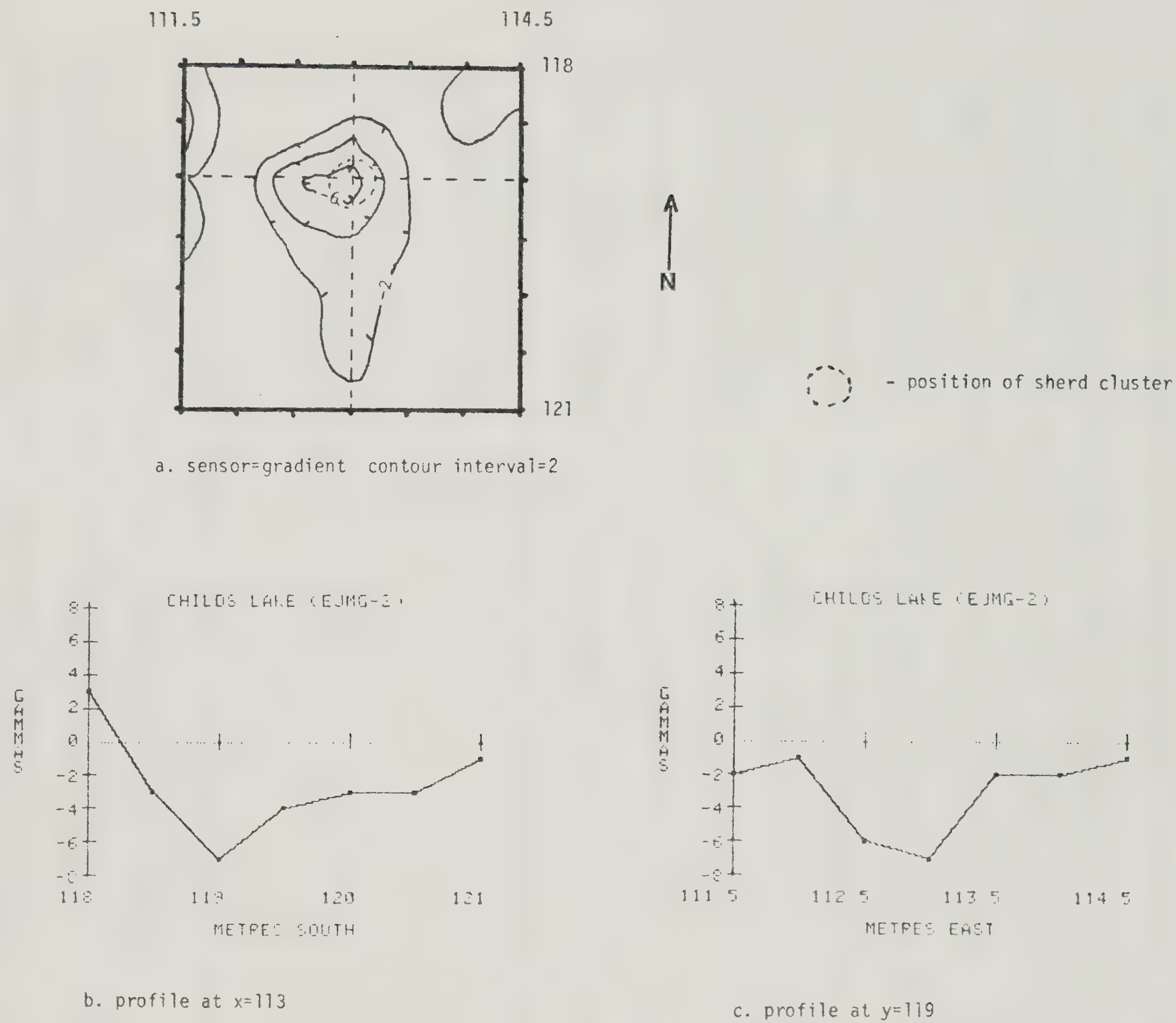


Figure 3.18 Childs Lake site magnetic resurvey of pottery sherd concentration, gradient (ZZ).

distant source, permitting a six gamma anomaly to be clearly demarcated directly over the pottery scatter (figure 3.18).

It is likely that the scattered pottery pieces were each too small to generate as powerful a dipolar magnetic field as would be expected from a whole pot. Instead, the randomly scattered pieces may have simply increased the magnetic field intensity in the local area only, because the north and south poles of each fragment did not nullify one another magnetically. A similar mechanism may also have contributed to the anomaly found over the lithic scatter at Munsungun Lake site 154-14, which was previously discussed. Based on this interpretation, it is possible that pottery fragments in aggregate could be so arranged as to largely cancel one another out, producing no perceptible change in the total field.

IV. Incorporating Magnetic Data into Excavation Strategies.

As previously stated, the culturally contagious nature of hearths makes them very amenable to productive excavation. This characteristic, which was strongly emphasized during the Munsungun Lake and Dickey-Lincoln surveys, has important implications for site sampling. Given the ability to determine the location of hearths (or even pottery clusters) an archaeologist can devise a

sampling strategy which will emphasize excavation in hearth areas, where evidence of human activity will probably be abundant, yet include peripheral areas which may yield other types of cultural remains not directly related to fire places.

As an example, consider a hypothetical single component site deposit on a level, featureless 20 metre square plot of land (figure 3.19). Occupation remains consist of two discrete lithic artifact scatters (A1 and A2). Within scatter A1 are the remains of three small fire hearths approximately 0.6 m in diameter (H1, H2, H3)>, two of which are near elongate lithic chipping features (CF1, CF2). There is no discernible quantity of bone within scatter A1. Artifact scatter A2 contains two hearth pits measuring more than one metre in diameter (P1,P2), and three localized clusters of broken bone in association with the fire pits (B1,B2,B3). Scatter A2 yields two to four pieces of broken bone per square metre over its extent.

A random sampling system was devised in which the plot of ground was divide into 20 rows and 20 columns. Each row was numbered from one to 20, as was each column. Metre squares or "units" were then randomly selected as required by randomly picking a number from one to 20 for a row, and then for a column. The two numbers then furnished the coordinates with which a unit was selected. Using this simple random unit generator, an arbitrary ten per cent

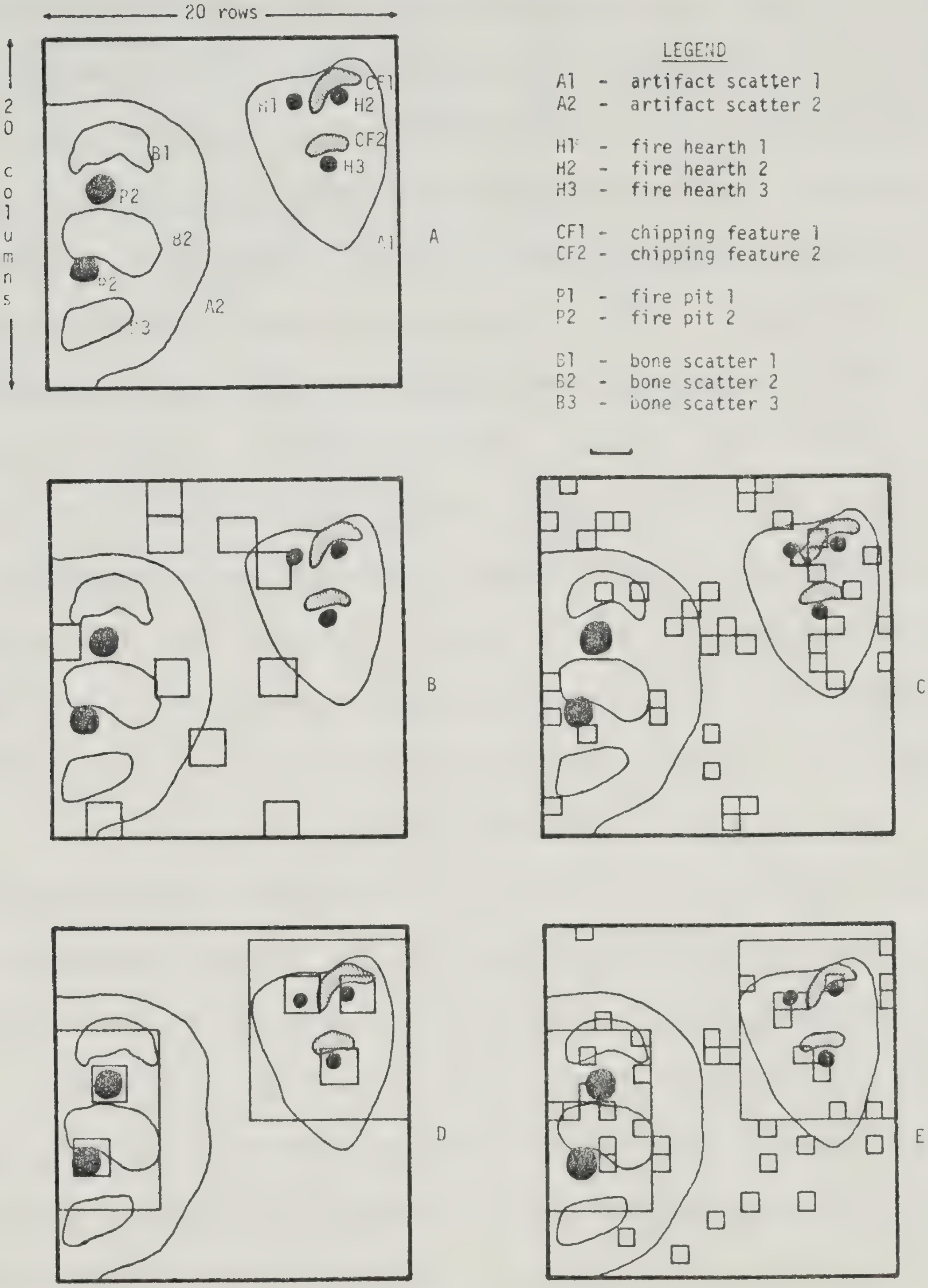


Figure 3.19 Hypothetical feature distributions and theoretical sampling approaches. A - unsampled 20 m square grid; B - grid sampled with ten two m squares; C - grid sampled with 40 one m squares; D - fired features located after magnetic survey; E - stratified grid sample.

sample of the exemplary "site" was "excavated".

The first ten per cent sampling procedure was initiated by randomly selecting ten two metre squares (figure 3.19b). This particular strategy, using large units, resulted in minimal sampling of locality A1 (2 units) and only restricted sampling of A2. Another random sample of the site using 40 one m squares (figure 3.19c) improved the sample results, in that contagious distributions A1 and A2 were more fully excavated over a broader area. Unfortunately, because the 40 units were distributed over the entire site, many fell outside of the contagious distributions, revealing no significant remains. Sampling the site in a totally random fashion did locate the two contagious localities, but the full range of features contained within them was poorly revealed.

If the three hearths and two fire pits are successfully delimited by magnetic surveying, the contagious nature of the artifact distributions around the hearths can be directly accessed in the course of feature excavation. In this case a random sampling design is not required since contiguous trenches can be excavated beyond the hearths in different directions to determine the extent of localities A1 and A2.

Unfortunately, this strategy places great emphasis on human activities related to fire. If other activities unrelated to the hearths took place on the site away from

localities A1 and A2, they would not be sampled using this latter strategy. As an alternative, it is possible to use the magnetic data to devise a stratified random sampling methodology in which all of the site is sampled, but the two localities more intensively. Such a strategy, for example, could entail sampling ten per cent of the twenty metre square area, with 60 per cent of the sample (24 square metres) being retrieved from localities A1 and A2 and the remaining 40 percent (16 square metres) coming from beyond those localities.

To stratify the site, two distinct sub-areas are designated, one containing the three hearths and the other containing the two fire pits. The extent of the sub-areas is defined by designating a rectangular area oriented with the sample grid and extending two metres beyond the edge of the most distant feature from the perceived centre of the clustered features, in each direction (figure 3.19d). This definition results in locality A1 being overlaid by a grid nine by ten m (90 square m, sample S1) and locality A2 being circumscribed by a grid six by ten m (60 square m, sample S2). Sixty per cent of the 40 square m allotted to sample ten per cent of the site is 24 units. Of the 24 one m square units being allotted to the two localities to be intensively sampled, and considering the relative proportions of each grid, locality A1 receives 14 one m squares and locality A2 receives ten one m square units. A

random sample is accordingly generated to place 14 units in sample S1, ten units in S2 and the remaining units (16) throughout the rest of the site (figure 3.19e).

Using this system, all three hearths and one of the two fire pits as well as both chipping features and two of the three bone features were intercepted in localities A1 and A2. The less intensive sample secured beyond the features, though producing no cultural material, nevertheless succeeded in defining the two localities, demonstrating that the latter were in fact discrete activity areas.

This example may not be directly applicable to any particular archaeological site. Nevertheless, it does demonstrate that with a little innovation magnetic surveying of a prehistoric archaeological site can accomplish much more than simply finding hearths to secure radiocarbon samples. For example, the work at Munsungun Lake, though originally planned with the express goal of securing charcoal for dating, was more valuable in defining apparent activity areas on parts of the site where intuitively such activity was thought not to exist. This revelation did not lead to the same type of sampling strategy as explained in the example, but it did stimulate more extensive excavation in areas which proved to be very productive archaeologically.

V. Conclusion

The successful use of magnetometry to locate hearths on prehistoric hunter/gatherer sites is primarily dependent upon the condition of the feature which is sought and its distance from a magnetometer's sensor. Hearths which have been severely weathered and physically disturbed are more difficult to detect magnetically than undisturbed features. If hearths are buried deeper than 1.5 m from the sensor only the largest ones will be resolvable amid the natural magnetic relief of a prehistoric site.

Based on the experiments at the beginning of the chapter, hearths which will be most detectable are ones which have been kindled repeatedly. This suggests that there will be less chance of locating fired areas on sites which were occupied for only a short time. On the other hand, camp sites of long occupation should be expected to harbour hearths producing very strong anomalies. In such cases it is possible that, under optimum conditions, fired areas can be reliably delineated at distances over two m from a magnetometer sensor.

Fired clay pots and clustered pottery fragments may be successfully located using magnetometry, if they are not buried too deeply in the ground. Magnetic surveys at Childs Lake located a number of buried pottery clusters at distances of up to 75 cm from the magnetometer sensor

(Badertscher 1982, personal communication). It is possible that heat treated lithic scatters and objects may produce detectable magnetic anomalies as well. Unfortunately, the evidence suggesting this, from Munsungun Lake, could not be verified and the results are at present ambiguous.

One potentially important area of investigation which was not pursued during the course of this study was the testing of various soils for magnetic susceptibility. In fact, though a number of soil samples were collected from several prehistoric sites the lack of proper equipment to perform the susceptibility measurements prevented any magnetic information being obtained from them. The research at Munsungun Lake could have very profitably utilized a portable susceptibility bridge to obtain soil susceptibility readings on site. The instrument could have been employed as excavation proceeded, so that potential areas displaying abnormal magnetic intensities could have been delineated, treated as hypothetical hearth features, and excavated accordingly. This would have permitted more confidence in placement of excavation units, and the localities could have been viewed as activity areas rather than test excavations simply searching for them. Areas which did not exhibit magnetically susceptible material could have been quickly abandoned, if strategy required it, and other areas tested.

To conclude, magnetic surveying of prehistoric sites

can yield useful information for certain kinds of archaeological research. However, survey applications must adhere to the limitations of the magnetic technique. The Caribou Island project represented less than ideal conditions for detecting hearths and research results were bound to be ambiguous, given the depth such features were anticipated to be buried. In a similar vein, surveying on sites of great antiquity, particularly in forested environments, may yield data which are difficult to interpret. This is because natural destructive forces have more time to visually obliterate hearths. These difficulties, however, are by no means common. In fact, the majority of forest sites, at least in northern North America, contain deposits which are relatively shallow (less than one-half m) and have not suffered environmental upheaval equivalent to that of Munsungun Lake or Dickey-Lincoln. Using magnetics, it is possible that many prehistoric sites could be effectively investigated in a short time period at a reduced labour investment, providing a proper research design is adopted and consistently adhered to during site investigation.

CHAPTER IV

MAGNETIC SURVEYING OF HISTORIC SITES

I. Introduction.

Historic sites in North America usually contain well preserved archaeological remains because they are only a few hundred years old. They are generally quite easily detected using magnetics, and consequently magnetic surveying of historic sites is often carried out in some parts of the continent. However, not much magnetic work has been done in Western Canada. It was therefore decided to test the feasibility of magnetometry in assessing historic archaeological remains in this area. The results of three such surveys are presented below.

II. Field Examples.

1. Cannington Manor

A. Problem: Cannington Manor was a small village settlement in southeastern Saskatchewan. It was established in the 1880's and consisted of more than a dozen major structures, including a hotel, school and flour mill. Though it thrived as a community during its first two decades, the village declined as a commercial centre

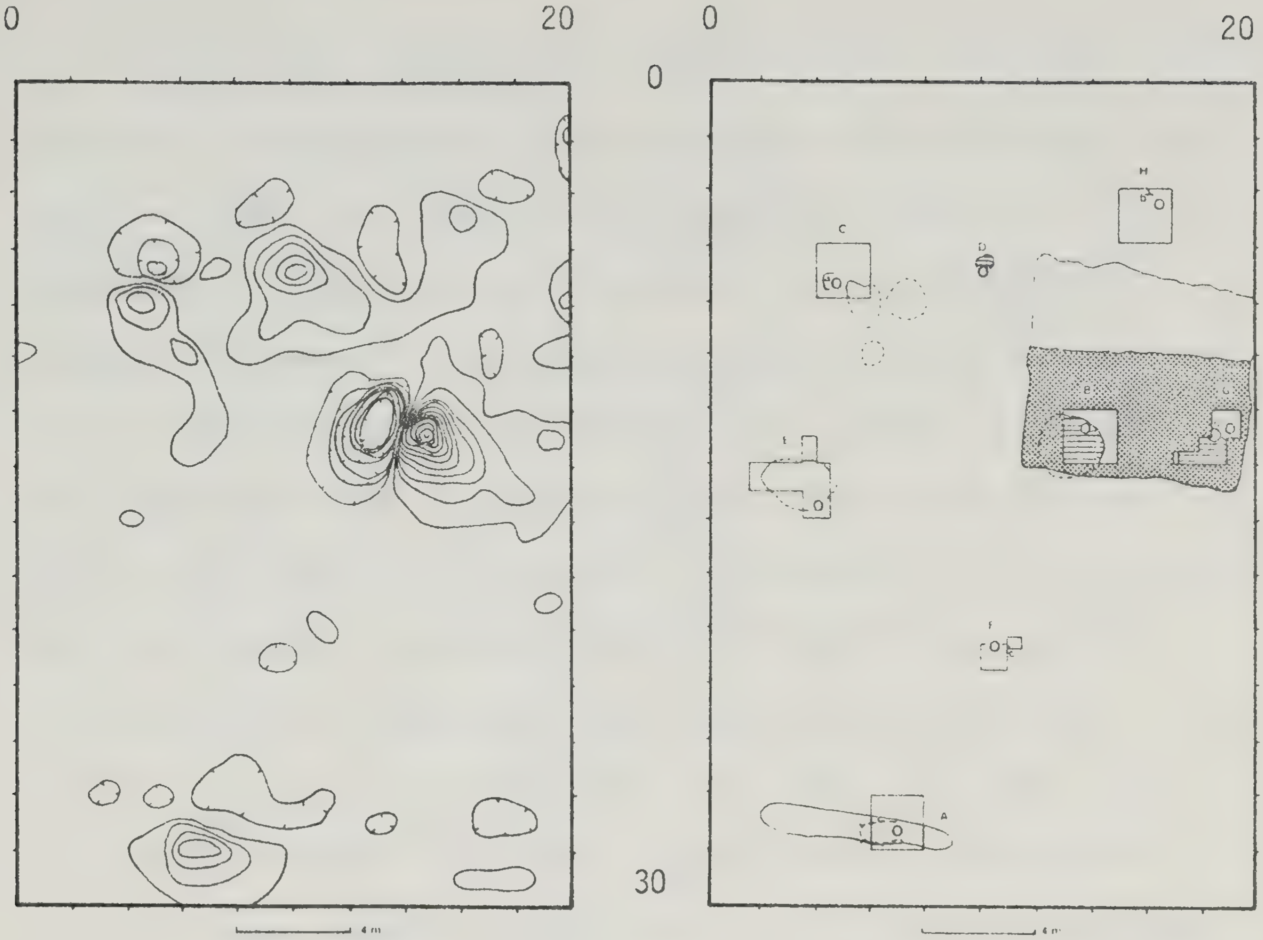
after 1900 and was entirely abandoned by 1915. All buildings but the church were dismantled or moved and most surface remains of the townsite were obliterated in the ensuing half century by farming activities which took place over most of the former village (Gibson 1978). The site was designated as an historic park by the Saskatchewan government in the 1960's and archaeological testing was carried out to determine the condition of the new park's archaeological resources. Because of its limited nature, this testing concentrated only on major structures and was not concerned with the total cultural resource inventory of the site (Gibson 1978).

In the late 1970's another program of investigation was initiated. At this time more attention was devoted to determining the types, quantity and condition of archaeological features and objects contained within the park boundaries, with emphasis placed upon the resources surrounding the known positions of the larger buildings. Unfortunately, traditional exploration methods involving linear trenching, random probing and test pitting required too much labour investment for the crew size available. Consequently an alternative method was chosen, involving magnetometry, to intensively assess the archaeological resource content of a particular area.

B. Methodology: To obtain some idea of the resource

potential of the many living yards in the park, three separate areas were magnetically surveyed, with the intent to use the results as indices to the condition of archaeological features for the rest of Cannington Manor Historic Park. One such area, a 20 x 30 m grid, was situated behind the remains of the old village teacherage. Prior to magnetic surveying, the grid was closely examined for suspicious ground features and any evidence of vegetation anomalies. In the process, a circular depression one m in diameter was noted, as well as a large rectangular area of heavy grass growth in the north half of the grid and a strip of light coloured vegetation on the grid's southern half (figure 4.1).

Magnetic measurements were obtained from the grid at one m intervals with the sensor at 65 cm above ground. Diurnal variation was controlled by referring to a base instrument after every station measurement. An older model magnetometer, which produced magnetic measurements that appeared to drift uncontrollably after several hours operation, was used. Because of this machine inaccuracy, and despite strong control of diurnal error, the survey accuracy was probably not more than plus or minus five gammas. Once data were gathered they were manually adjusted and plotted at a contour interval of ten gammas (figure 4.1).



a. relative magnetic intensity in gammas. contour interval=10, hatchured contours start at 140.

b. excavations and features within surveyed grid.

KEY

o - anomaly location

····- suspected feature outline

——- excavation unit

- abnormal vegetation cover

- heavy vegetation cover

a - metal hoop fragments

b - pitchfork head

c - cast iron plate

d - small depression

N

Figure 4.1 Cannington Manor Historic Park, Teacherage grid.

C. Results: Although a coarse contour interval was employed in mapping and interpreting the teacherage grid data, a number of significant magnetic anomalies were identified. The source location for each anomaly was roughly determined from data on hand; no repeat readings were obtained for specific anomalies. Upon identification, all anomalies were investigated by excavation of the cultivation zone and removal, if required, of the Ah and B soil horizons. As well, selective soil cores were retrieved when excavation was considered unnecessary. The results of these explorations are shown in table 4.1.

Of the eight anomalies investigated, six (A-E,G) appeared upon limited examination to be related in some manner to remains of former structures or activity areas such as refuse dumping. Anomaly D, in the vicinity of the depression found during the surface survey, was probed and found to contain large rocks and mixed earth fill, and was interpreted as a well. Two anomalies (F and H) were caused by isolated metal.

D. Conclusion: As previously stated, the goal of the Cannington Manor exploration program was to determine the extent, range and state of preservation of archaeological features that were postulated to rest in the area of a number of former structures. Based on the example just presented, and the results of two other test grids, the

Anomaly	Location south	Location east	Source	Archaeological Interpretation
A	27.5	7.0	metal fragments	refuse midden
B	12.5	14.0	metal filled depression	cellar pit?
C	7.5	4.7	barrel hoop, nails	refuse midden
D	6.5	10.0	rock, mixed soil	buried well shaft
E	15.5	4.0	clay deposit, metal	undetermined remains
F	20.0	10.0	cast iron plate	isolated find
G	12.5	19.0	depression fill	undetermined
H	4.5	16.5	pitch fork, nail scatter	isolated find

Table 4.1. Magnetic anomalies investigated at Cannington Manor Historic Park.

research program indicated the following:

1) Archaeological features and objects remained intact beneath the plough zone despite a prolonged period of cultivation, and thus were amenable to archaeological interpretation

2) Areas in the vicinity of all structures investigated contained archaeological features suggestive of intensive human activity related to day-to-day living.

3) Based on the frequencies of features discovered on all grids surveyed, most of the structures in the park probably harbour features of archaeological interest.

These conclusions could not have been stated as confidently if the exact location of many of the features detected magnetically had not been made available for direct examination through excavation. To achieve as confident a statement using traditional strip trenching and test excavation would have required a much greater investment in time and labour to uncover as many archaeological remains.

Beyond the research objectives, the survey suggested several additional points for comment. Many of the archaeological features were detected because they contained metal. Although the presence of metal is often

detrimental to most magnetic surveys, on some sites iron alloy artifacts may be in association with archaeological features and serve as a means of locating them. Iron artifacts produce very distinct anomaly configurations. Thus, if an iron object is buried in an artificial pit, such as a privy hole or cellar, the anomaly it generates can be used to determine closely the minimum depth of the feature it is contained within much more accurately than the anomaly generated by the feature itself. The example also reinforces the idea that magnetic surveying is more revealing when it is carried out tactically by verifying anomalies by resurveys and other tests.

The magnetic data from the teacherage grid at Cannington Manor would have been of very limited interpretive use without subsequent excavation because the survey accuracy was relatively poor and the methods of interpretation were very simple. If even plus or minus three gammas accuracy had been achieved in gathering data, and upper and lower data been secured for preparation of gradient maps it is probable that other important features may have been distinguished and properties about the larger features more clearly determined without excavation. Also, if statistical manipulations accompanied by machine plotting had been undertaken, more accurate source positioning may have been effected. As the complexity of the archaeological resources increases, accuracy combined

with sophisticated analysis becomes increasingly critical to assume meaningful interpretion of the archaeological content of a site.

2. Souris Mouth (DkLv-4, DkLv-9)

A. Problem - DkLv-4 and DkLv-9 are the remains of fur trade forts located in Southwestern Manitoba, on the Assiniboine River. Much of DkLv-4 is under cultivation, although an unknown portion appears to be undisturbed near the river bank which lies adjacent to the agricultural land. Because the Manitoba provincial government was sponsoring a research program to assess the archaeological potential of historic remains in this area, including those which rested on privately owned farm land, a non-destructive assessment program was required that would provide some idea of the cultural resource potential. Accordingly, the magnetic survey which was implemented on the DkLv-4 reflected the following research requirements and goals:

1) document the archaeological resources that might remain intact beneath cultivation,

2) determine the amount of archaeological resources lying outside of the cultivated area,

3) discern a pattern of archaeological features suggestive of structures and their associated out-features,

and

4) recover as much data about the archaeological resources as possible without implementing exploratory excavation.

Item number four was especially critical in the case of DkLv-4, because the owner of the land did not wish excavation to take place during the survey, since the field was freshly planted. Because DkLv-9 was believed to be undisturbed by cultivation, only research goals three and four applied to the survey work implemented on this site.

B. Methodology - On DkLv-4, a number of 10 x 15 m grids were established over the site in areas along the river bank and in the cultivated field. Magnetic measurements were obtained at sensor heights of 60 and 30 cm per station, and base checks were taken every two minutes, or more frequently as required by the ambient field fluctuations. Survey accuracy was determined to be plus or minus two gammas. A similar methodology was applied on DkLv-9.

Survey work on these two sites represented the first test of interpreting magnetic data in a field situation using a microcomputer. At first data were collected during the day and entered into the machine at night in the field camp. Maps were then produced and printed out. Unfortunately, the data entry process took longer than

anticipated and the daily rate of data collection far surpassed the crew's ability to enter and process magnetic information at night. A serious lag developed between data accumulation and data interpretation. As well, the survey program concentrated too much upon collecting data and not enough on verification of anomalies. This resulted in too many data being accumulated for the microcomputer to process in the short field time allotted for the site (about three days), and therefore magnetic verification of anomalies was not carried out. Instead, the magnetometer was used simply to collect more primary data from nearby archaeological sites. However, on DkLv-4 a brief period of field verification using a probe and metal detector was implemented with very important results.

It was unfortunate that excavation of presumed features detected by the magnetometer was not allowed. However, probings of anomaly areas was permitted on DkLv-4. These consisted of soil cores obtained in 10 cm depth increments until all evidence of cultural features disappeared in soil columns or the length of the soil coring tool (90 cm) was reached. The metal detector sensitivity was limited to roughly 20 cm depth, although larger pieces of metal could be detected to about 30 cm. In at least one case metal was struck by the soil probe at a depth that was not detectable by the metal detector, although the iron-based material had been sensed quite

clearly by the magnetometer.

C. Results

i. DkLv-4

Figure 4.2 shows the results of sampling a particular block 27 x 30 m in extent with a magnetometer, soil sampler and metal detector. Prior to survey and field verification, the only archaeological features visible were a shallow mound of earth, overgrown with vegetation, which appeared to be the remains of a cellar, and an elongate alluvial soil accumulation at the edge of the cultivated field, which did not appear to be a structural feature. The magnetic survey revealed a number of anomalies which were analyzed in the field and marked for probing and secondary survey with a metal detector. The results of the tests are shown in table 4.2 and 4.3.

The available data outline areas which could be critically examined when excavation is actually planned. These particular areas are defined in figure 4.2, and, on the basis of soil samples, contain remains of structural origin, or features associated with structures and living areas. Other anomalies, when tested with the metal detector, appear to be caused by metal and are of secondary importance, probably not requiring excavation. Probed

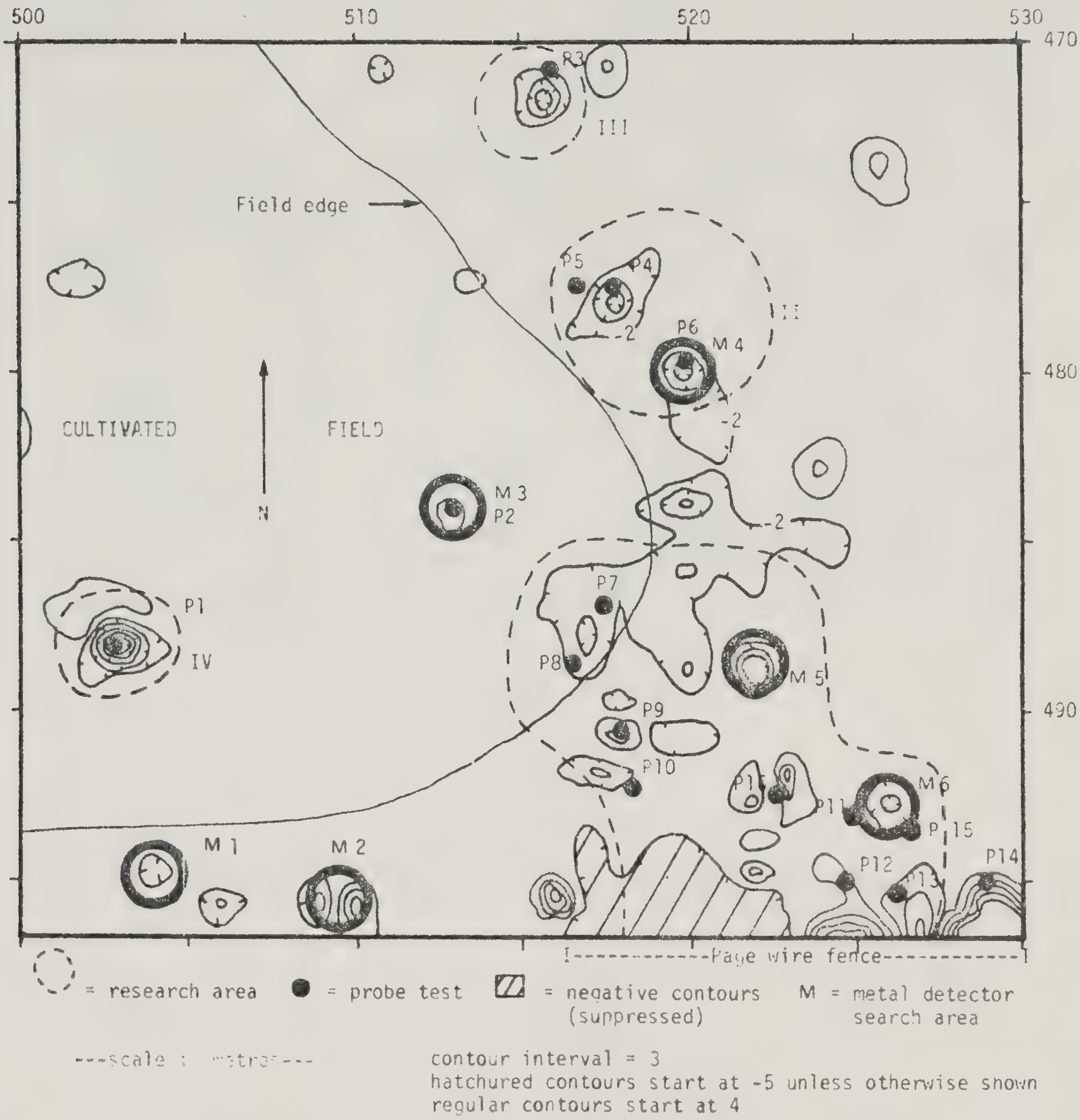


Figure 4.2. Magnetic interpretation of test grid at Souris Mouth site DkLv-4.

Assay	Location south	Location east	Source Depth	Archaeological Source
1	495.0	504.0	10 cm	metal detected (can)
2	496.0	510.0	12 cm	metal cluster
3	484.0	512.0	-----	no source detected
4	480.0	520.0	>15 cm	source beyond range of instrument?
5	489.0	520.5	-----	source beyond range of instrument?

Table 4.2 Summary of findings from metal detector sweep over selected anomalies on DkLv-4 test grid.

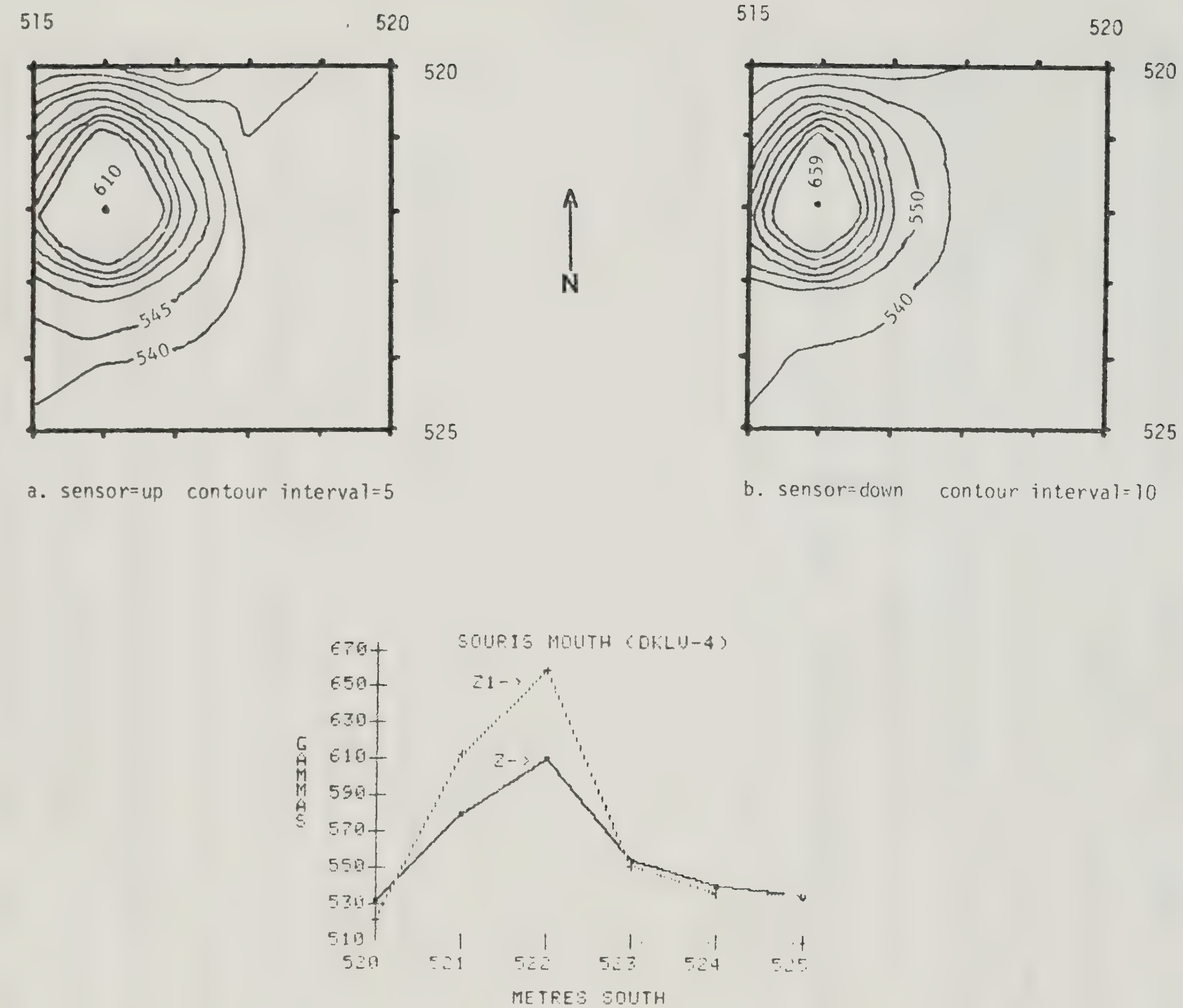
Probe	Location south	Location east	Depth (cm)	Matrix	Archaeological Source
1	488.0	502.5	>90	Ah, mortar, cinders	burning pit
2	484.0	513.0	40	Ah, B	none found
3	471.5	516.5	35	Ah, B	none found
4	478.0	518.0	>90	Ah, mortar, ash	privy pit?
5	478.0	517.0	40	Ah, B	none found
6	480.0	520.0	35	Ah, B, mixed earth	buried metal plate
7	487.5	517.0	35	Ah, mortar, wood frags	buried foundation
8	489.0	516.0	60	Ah, mortar, mixed earth	buried foundation
9	491.0	517.5	>90	Ah, mortar, cellar fill	cellar
10	493.0	518.0	35	Ah, B, wood frags	none found
11	493.5	525.0	35	Ah, B	none found
12	515.0	524.0	30	Ah, mortar, mixed earth	structural remains
13	515.5	525.5	30	Ah, mortar, mixed earth	structural remains
14	515.0	527.5	30	Ah, B	none found
15	493.5	526.0	50	Ah, mixed earth	localized depression
16	493.0	521.5	>90	Ah, mortar, cellar fill	cellar

Table 4.3 Results of probe test of DkLv-4 test grid.

anomalies which are ambiguous require magnetic re-assessment before excavation.

The three and possibly four areas suggesting the presence of archaeological features probably represent less than 25% of the area of the entire grid. This much more localized research focus enables exploratory excavation to be carried out intensively in areas believed to be productive. Other sampling strategies can be used in magnetically unproductive areas.

Elsewhere on DkLv-4, a number of anomalies were discerned which represent remains of structures or other cultural features. One anomaly of particular interest was found on another part of DkLv-4, appearing as a very powerful monopole (figure 4.3). A curious aspect of this anomaly is its configuration in combination with its extreme intensity, particularly in the lower sensor poition. Although the anomaly was only coarsely sampled by the magnetometer, the profile for the upper and lower data sets passing through its centre do not conform to those of the monopole model displayed in chapter 2 (figure 2.3b). The profiles show that there is considerable increase in intensity at positions 521 and 522 m south, but that otherwise there is little change in intensity between the two values. The suggestion is that this anomaly is somewhat similar to that generated by the pottery scatter at Child's Lake, only with far greater intensity.



a. sensor=up contour interval=5

b. sensor=down contour interval=10

c. profile at x=516 ■=sensor up +=sensor down

Figure 4.3 Souris Mouth site DkLv-4, magnetic intensity over possible brick cluster.

After repeated readings surrounding the anomalous field ensured that the anomaly was represented only by a monopolar "high", a series of soil samples were obtained from the centre of the anomaly using a two cm diameter soil coring probe. The cores revealed a 10 to 20 cm layer of humus from the cultivation zone. Below that point, samples of soil mixed with brick particles and sand were pulled up. A solid obstruction was encountered at 60 cm below ground surface, possibly consisting of brick or rock material mixed in with a matrix of charcoal and mortar. The source for this anomaly, though not fully examined, appears to have been a collection of bricks or possibly a brick structure.

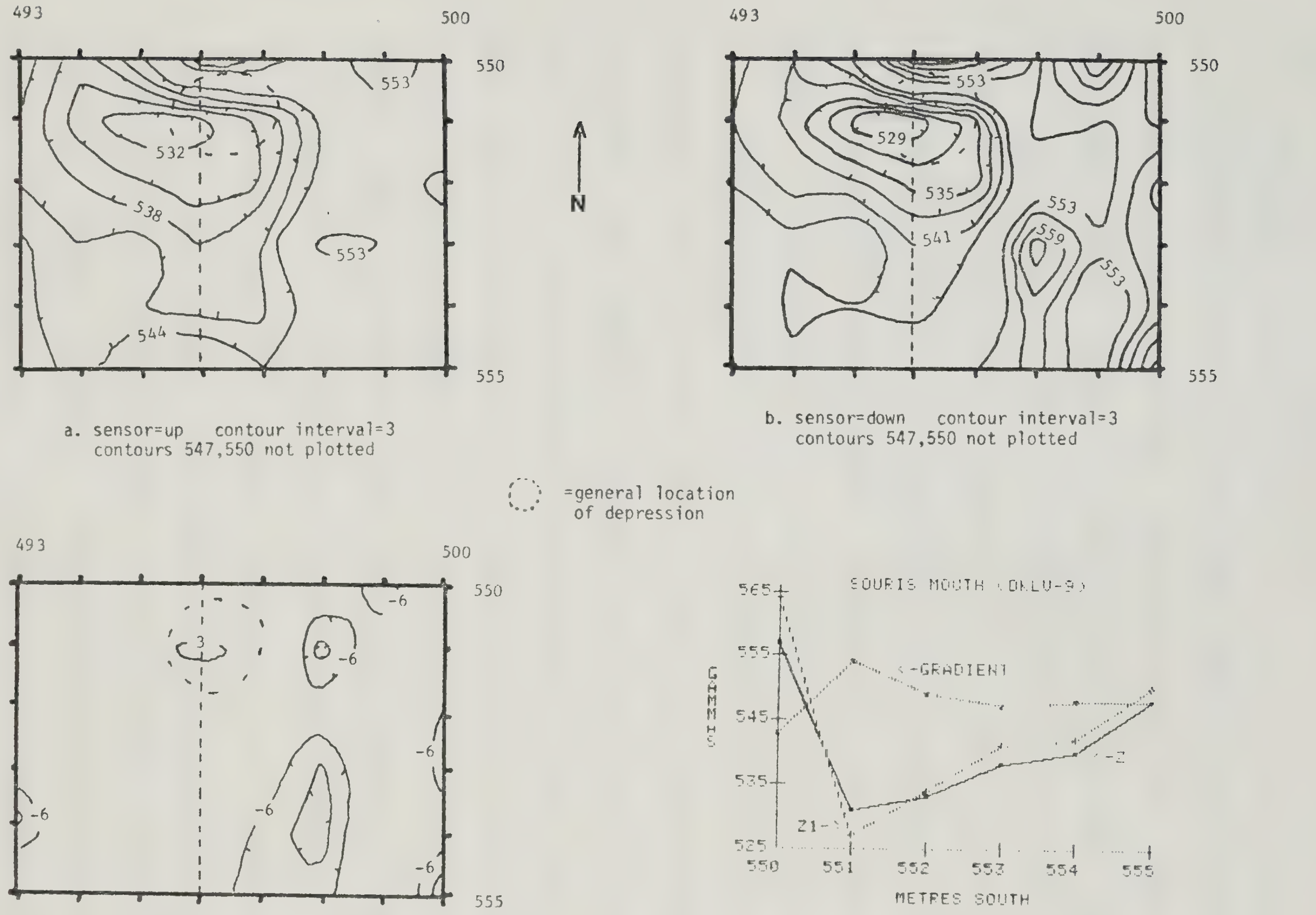
ii. DkLv-9

Due to lack of time, magnetic anomalies discerned on DkLv-9 were not re-surveyed or probed. However, because the site was undisturbed, buried archaeological features could be visually located by searching for anomalous vegetation growths and correlating their locations with anomalies found during magnetic survey. A number of depressions were encountered during the time that magnetic data were being collected. One of these, several metres in diameter and nearly a metre deep, produced a significant magnetic anomaly in both the upper and lower sensor data

sets. However, gradient data did not significantly record the anomaly (figure 4.4). This is because gradient readings are not sensitive to sources which produce magnetic fields substantially broader than the distance between the upper and lower sensor positions. Gradient readings were found to be very useful on DkLv-9 in differentiating buried features such as pits and cellars from others such as partially buried fireplaces and garbage middens filled with iron. Generally, the latter types of features generated magnetic fields which were somewhat more intense in the lower sensor position than in the upper position. The gradient of these readings was thus quite distinctive.

D. Conclusion - The success of the magnetic program at DkLv-4 can best be determined by using the resulting data to answer the questions addressed at the beginning of this section:

a) Archaeological resources in the cultivated area - Limited probing within the exploratory grid did not reveal much evidence of archaeological remains in the cultivated field, which lends support to the results of the magnetic survey in that area. With the exception of one prominent anomaly, which appears to have been caused by a pit of some kind, no other verifiable archaeologically related anomalies could be detected in the cultivated area. This



a. sensor=up contour interval=3
contours 547,550 not plotted

b. sensor=down contour interval=3
contours 547,550 not plotted

c. sensor=gradient contour interval=3
contours -3,0 not plotted

d. profile at x=496 (mean field intensity
of 550 added to gradient values)

Figure 4.4 Souris Mouth site DkLv-9 showing upper sensor (Z), lower sensor (Z1) and gradient (ZZ) magnetic intensity over a visible cellar depression.

suggests that cultivation has seriously obliterated all magnetically detectable archaeological remains that were once present in the field.

b) Archaeological resources beyond the cultivated area - Magnetic data, strongly supported by probe tests, suggest that many archaeological features exist outside the cultivated field. Such features appear to consist of pits, cellars and foundation remains, all buried beneath 15 to 30 cm of humic soil. For this grid, archaeological resources are especially concentrated in its southeast corner and appear to be related to a buried building foundation.

c) Archaeological patterns suggestive of structures- Although the cultivated field lacks any archaeological features, the uncultivated portion contains cultural remains. In the southeastern portion of the grid, structural remnants, consisting of a buried cellar plus a broad, buried depression, are vaguely outlined, and soil samples yielded mortar, wood and ash fragments (see figure 4.3, area I). A second area to the north about 5 to 8 m (figure 4.3, area II) appears to be a pit, containing a collection of buried iron objects in an uncertain association. At the extreme north end of the grid a magnetic anomaly suggests the presence of another pit, although this could not be verified by probing. The pit lying 10 m to the west in the cultivated field may also be related to the structure complex. A few strategically

placed test excavations should be able to document the relationship of the mortar scatter to the depressions in the southeast corner of the grid, and their relationships to the clustered features lying to the north.

Several areas of this particular grid should have been more intensively investigated by magnetometer so that the distribution and nature of features could have been more accurately determined. However, selective soil sampling did significantly improve the original assessment of the grid provided by magnetics. As well, the metal detector tests, by eliminating anomalies caused by surface metal, enabled the magnetic grid to be interpreted with greater confidence so that perceptible magnetic patterns could be discerned. These supportive testing procedures required little effort to implement, once major features were delineated, yet they were necessary to substantiate the sometimes inconclusive results provided by the magnetic data alone. In fact, in almost all cases involving assessment of historic sites, it is probable that secondary exploratory methods which supplement primary magnetic data will significantly improve the interpretation of the site, especially if selective intensive magnetic re-surveys are also implemented.

On DkLv-9, despite the inability to make actual sub-surface tests, secondary surface indications of archaeological features agreed well with the mapped

magnetic data. In some cases, using magnetic data from obvious features as models, fully concealed archaeological remains were magnetically delineated and subsequently located (S. Hamilton, personal communication, 1982).

3. Mercy Bay, Banks Island (Investigator Beach)

A. Problem - Investigator Beach is a site containing the remnants of a cache of goods left by the crew of the H.M.S. Investigator. The Investigator, a ship taking part in a Royal Navy search in 1853 for the missing Franklin Expedition, was beset in the ice of Mercy Bay on Banks Island, N.W.T.. Prior to abandonment, the ship's supplies, mostly in kegs, were cached on a beach on the west side of the bay. After the Investigator's crew was rescued, the remaining supplies were periodically visited by various groups of Copper Inuit for the ensuing 30 years. These people, living far to the south on the mainland, undertook the long journey to Mercy Bay specifically to obtain large pieces of wood and iron from the kegs and a few crates, commodities which were otherwise totally unavailable in that high latitude (Hickey 1981).

Though archaeological preservation in the Canadian Arctic is very good, the only extant remains of the cache consist of clusters of splintered barrel staves and a badly weathered coal pile. The barrel staves presumably mark the

areas where the Inuit broke up casks for their contents and desirable wood and iron.

A previous survey of the cache site in 1980 had discovered no sign of habitation by Inuit in the area, despite the clear evidence of their presence at the cache. Intensive monitoring of the ground surface, however, revealed broken bits of metal and glass in certain areas, which suggested intensive human activity. Unfortunately, metal fragmentation was extensive and light vegetation and soil cover visually obscured all but the largest metal pieces. Thus, it was impossible to discern metal working areas with enough confidence to actually map them. What was required was a means of locating areas where metal working took place on the site, and determining the relative amounts of metal working that occurred at each activity area.

Since Mercy Bay is in a very remote part of the arctic, exploratory excavation could not feasibly be implemented to locate these areas. Instead, a testing program involving a magnetic survey of parts of the site was initiated, to determine if metal working areas could be delineated and relative degrees of metal working intensity identified using magnetic interpretation techniques.

B. Methodology - The survey program was limited by the availability of transportation from the main archaeological

base camp located about 100 km south. In the course of a rapid shoreline survey of northern Banks Island, a magnetometer crew of two were set down by helicopter at Investigator Beach. The helicopter was to return for the crew in 24 hours. In this space of time as much magnetic data as possible were to be collected. Since survey time was limited, no interpretation of the data was to take place, although some major surface features of the surveyed area were to be mapped.

Although several separate barrel stave scatters were noted on the site, only one was investigated in the day long period. A 30 x 40 m grid was laid over that particular scatter and divided into 10 x 15 m sub-grids. A magnetic survey was then undertaken with readings being acquired at metre intervals at sensor heights of 60 cm and 30 cm. Diurnal magnetic variation was monitored using base checks every 90-120 seconds.

Much of the survey was hampered by extremely large diurnal magnetic fluctuations, some as great as 30 gammas change per minute (see figure 2.1). In ordinary circumstances, the survey would have been abandoned, even though repeated base monitoring disclosed that the variation occurred at a fairly constant rate that could be compensated for if single sensor survey accuracy of plus or minus four or five gammas was acceptable. Because iron distributions, which ordinarily generate strong magnetic

fields, were to be assessed, this survey accuracy was deemed acceptable. Gradient data largely filtered out the diurnal fluctuations, however, and in any case, very strict time constraints dictated that the survey continue, if at all possible, in spite of magnetic storms.

A total of six 10 x 15 m grids were eventually completed. Probably the entire 30 x 40 m area could have been assayed had an untimely sensor cable breakage not delayed the survey. The data from those six grids were then entered and assessed using the Magnetic Data Processing Package software on the base camp's field computer.

C. Results - Although fairly detailed observations were made of the metal content of the survey area, only a few firm correlations can be made between observed anomalies and actual observed metal scatters. An overall assessment of the 30 x 40 m grid appears in figure 4.5 and table 4.4.

D. Conclusion - At the outset, based on these preliminary data, definite anomaly clusters are apparent in certain parts of the survey area. In particular, these clusters are prevalent in grid #5, well away from the area where maximum barrel stave splintering took place. Based either upon direct observation or inference through anomaly

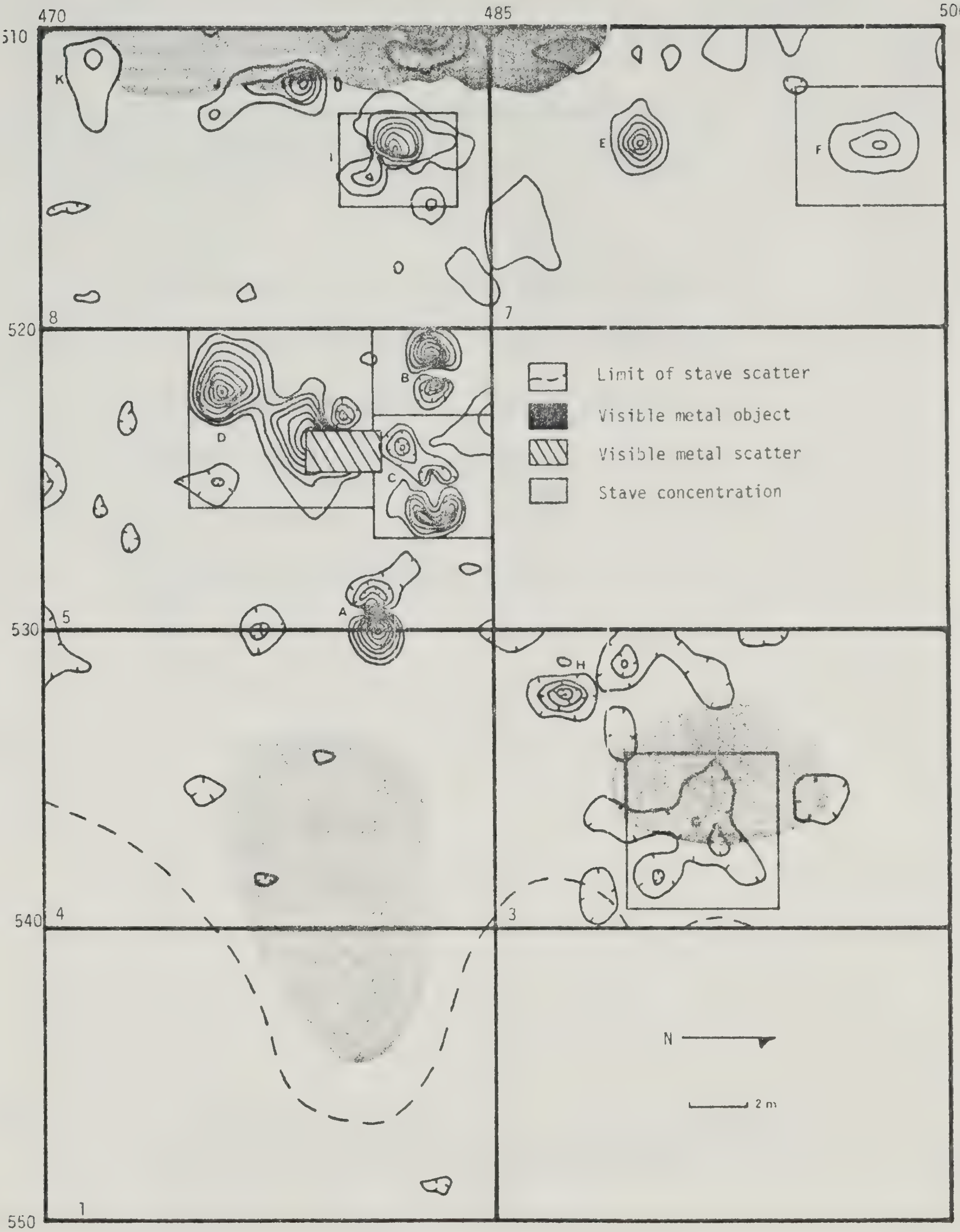


Figure 4.5 Investigator Beach site, on the west shore of Mercy Bay, Banks Island, N.W.T. showing gradient (ZZ) magnetic Intensity. Contour interval=5, 0 contour suppressed, hatchured contours start at -5. Letters refer to research localities.

Anomaly	Anomaly Type	Source
A	Dipolar	Tin Can
B	Dipolar	Single Object
C	Diffuse Dipolar	Metal Cluster
D	Diffuse Dipolar	Metal Cluster
E	Monopolar	Metal Scatter
F	Monopolar	Metal Scatter
G	Diffuse Monopolar	Metal Scatter
H	Monopolar	Metal Scatter
I	Dipolar	Single Object

Table 4.4 Summary of magnetic anomalies and their possible sources at Investigator Beach.

analysis, most anomaly sources appear to be caused by clusters of iron which generate a number of interacting dipoles, which can be separately delineated by comparing lower and gradient sensor data. Thus, weak monopolar anomalies are inferred to have been generated by many tiny pieces of metal. These metal bits create dipolar anomaly configurations that resemble a net positive or negative field distortion at a one metre interval of assessment. This appears to be the case in anomalies F and G and perhaps part of anomaly D. These anomalies may represent areas of intense metal breaking, especially of "tin" containers. Whether this metal breaking has been caused by human action or some other set of forces can not be determined from data at hand. Direct observation is required.

Because magnetic data were secured at a relatively coarse interval, direct interpretation of many anomalies is difficult. If continued research is to be carried out at Mercy Bay, on-site processing and plotting of data should be instituted so that areas bearing magnetic anomalies can be magnetically re-investigated at closer grid intervals. In this way smaller pieces of metal suggestive of metal working can be better discriminated for within areas which contain large pieces of metal.

III. Conclusion.

Archaeological research on historic sites in North America currently places heavy emphasis on excavation of not only major structures on a site, but also their associated outfeatures. These outfeatures (pits, trenches, shed remains, refuse middens) provide a basis for determining subtle social patterns which were manifested by the people residing in the main structure and carrying out day to day activities. Thus, an archaeologist who intends to pursue excavation of a site with an anthropological perspective must investigate lesser archaeological features with as much concern as the main structural remnants.

Employing conventional testing techniques to search for buried historic features is always a time consuming and frequently unproductive endeavor. The magnetic technique, however, by virtue of its fast and relatively effortless means of acquiring field data, and the automated way in which these data can be usefully displayed for interpretation, is far more amenable to current archaeological exploratory needs than systematic probing, trenching or test pitting. Using magnetic data as a basis for selectively exploring areas suggestive of cultural features permits more time to be spent conducting extensive investigations and less time simply trying to find them. In addition, though sometimes producing ambiguous results, magnetometry does detect many archaeological features

missed by sampling methods of other types which require great effort and can therefore only be applied sparingly. Finally, the magnetic method is non-destructive. On some sites, particularly those which are specially landscaped for public interpretation or are prone to visitation by unscrupulous artifact collectors, exploratory excavations may be undesirable. The magnetic technique enables excavation to be minimized, or to be replaced by less destructive intensive sampling techniques such as probing.

Magnetic data retrieved from a survey of an area can often provide specific information about an object or feature other than its general location within that area. At Mercy Bay the magnetometer was particularly useful in defining areas which harboured broken up metal. At this site, a systematic survey using a metal detector would have detected metal; unfortunately metal detectors do not provide a reliable means of quantifying the amount of metal they are detecting. This was a limitation, which would have rendered the quick visit to the site less useful.

The field interpretation experiment using the microcomputer demonstrated the utility of such a system when a tactical magnetic survey is implemented. Unfortunately, it was difficult for data processing and interpretation to keep pace with the rapid acquisition of data. This particular problem, which is endemic to surveys on both historic and prehistoric sites, will be dealt with

in the following, final, chapter.

CHAPTER V.

THE PRACTICAL VALUE OF MAGNETOMETRY AS AN ARCHAEOLOGICAL TECHNIQUE

Many archaeologists are attracted to magnetometry because it offers an opportunity to "map" the invisible sub-surface of an archaeological site. Archaeologists involved with magnetics concluded years ago that this was not a feasible expectation. The methodological approach of remote sensing may be useful in providing a general assessment of the presence of cultural remains on a site but implementation of a single remote sensing technique will rarely furnish a detailed cultural inventory. In fact, results of this thesis research have shown that an archaeological problem involving magnetometry can most successfully be investigated using the combined methodological approaches of remote sensing and archaeology.

The examples in chapters three and four demonstrated a wide range of problems to which magnetometry can be applied. Most of the applications concerned simple prospection. Locating archaeological features helped produce objective research designs for the excavation of sites. The key approach involved the use of locational data to augment more conventional methods of archaeological examination, in many cases making them more efficient.

Magnetometry can potentially be used to identify some archaeological features without excavation, but in many cases magnetic data are so ambiguous that they cannot be conclusively equated to anomaly signatures of any specific feature type.

What chapters three and four did not do was demonstrate the practical problems which must be overcome when a remote sensing technique such as magnetometry is applied to an archaeological site. The pragmatic aspects of magnetometry such as the cost of a survey, the number of people it requires and how quickly it can be done must be known so that its advantages can be compared with more traditional archaeological search techniques.

A. Implementing Magnetic Survey

An archaeologist willing to use a magnetometer to augment a research strategy must know how easily the technique can be implemented. Gathering field data is a relatively simple operation which any individual with field experience can easily master in only a few hours. The critical problem is data assimilation. As previously explained, a large amount of data are recovered during any magnetic survey. These data must be mapped or profiled to be interpreted and the more data that are collected the more unmanageable the task becomes, especially in a field

situation.

To overcome this data management problem I first turned to a university computer to manipulate and plot magnetic data. This move greatly improved the speed with which data could be interpreted, although the automated procedure was expensive and seriously degraded the continuity of field work because of the dependency which was acquired for a remotely located computer facility. These limitations also significantly hampered the integration of magnetic surveying with other means of site assessment.

The mainframe computer posed another problem which limited its usefulness as a means of processing magnetic data. When such facilities could be accessed, their complexity of operation required that a considerable expertise in computer operation be acquired before magnetic data could be efficiently processed. The system was especially intimidating to a person unfamiliar with its operation. Thus, a novice could never be expected to use the data processing system to analyze magnetic data, even if the person could sufficently master the techniques of acquiring them. Because of these inadaquacies, the mainframe-based data processing system was abandonned in favour of a simpler microcomputer system which was converted for operation in the field, complementing the tactical strategy for magnetic surveying which was quickly

being adopted.

The field processing system, because it is fast, easy to operate (even for a novice) and always accessible, makes it much easier for an archaeologist to gather magnetic data and have them available in interpretable form. The system also lessens the technical expertise required by an archaeologist to successfully implement a large survey without professional help by computer programmers and operators.

If magnetic data can be successfully gathered, processed and presented, the only technical aspect most archaeologists will be unsure of is their interpretation. The mathematical knowlege required in interpreting an anomaly to determine vertical and horizontal location, shape and composition can be quite intimidating. However, as previously stated, archaeological magnetic anomalies are very rarely amenable to rigourous analytical treatment. Beyond a rudimentary understanding of how and why magnetic anomalies are produced on archaeological sites, more comprehensive knowledge is rarely required to interpret most sites, since the culturally derived sources are so ambiguous in composition that beyond determining their location little else can be stated. Once location of features is known, archaeological testing methods can be brought to bear which can very effectively examine them, without resort to complex magnetic theory.

This is not to say that interpretaton is always a simple affair. Often features occur in great profusion on a site, generating magnetic fields which interfere with one another, producing anomalies which must be closely examined to determine the number of sources and their actual location. This may require some expertise on the part of individuals experienced in interpreting magnetic anomalies in archaeological contexts. The more complex a site is, the more difficult it will be to interpret and the more experience an individual will require to analyze the data efficiently.

B. Time and Cost of Implementation

A nagging concern of many archaeologists is the time that it takes for magnetic data to be acquired, interpreted and applied to site investigation, and the cost such work will entail. This is a legitimate concern which was carefully addressed during the many surveys which were carried out for this thesis. Although the rate of data acquisition varied substantially with terrain, vegetation cover and the magnetic environment, an average of two 20 m square grids could be covered daily using a single magnetometer to collect two magnetic readings per metre interval. This represents about 1800 readings acquired in roughly five hours, using an experienced crew of two. By

spending the rest of the day using a microcomputer to analyze and plot data, analysis could keep pace with data acquisition. Without the computer, an exra individual was required to hand plot the data to keep the process current with the survey. This represents a survey conducted using a minimal investment in equipment and labour and is probably the most efficient scheme of survey that can be implemented.

Organizations which conduct commercial magnetic investigations can survey more area per day (data processing is done remotely) but at a much higher cost. The actual cost of the two man survey team per day is the labour expense and equipment rental. High quality proton magnetometers can be rented on a monthly basis at about 10% of their cost. The instrument used for most of the field work in this thesis was valued at $4000.00 and was rented at between $350 and $500 per month. The minimal microcomputer system capable of operating the Magnetic Data Processing Package in the field is worth about $3500, or $350 per month. Equipment rental probably represents a small fraction of the cost of such a survey in comparison to salaries. Using two individuals at an average of 800 square m per day surveyed, in five days a large site (4000 square m) can be magnetically examined and the data processed and ready for interpretation. Assuming that significant anomalies were identified, resurveyed and

tested using probes and test excavations, the rest of the month could be spent in actual excavation of specific features or areas designated on the basis of feature locations. For an investment of approximately $800.00 for equipment rental, plus the initial five days labour for two people, many archaeological sites can be assessed fairly thoroughly and probably more effectively than by any other site analysis technique. The assessment information can then be used to design a full scale site investigation using a larger crew. This summarizes many of the results that were achieved using magnetic surveying on a number of archaeological sites, both historic and prehistoric, during the course of the field work for this thesis.

If a very large site, or number of sites require magnetic assessment, the optimal survey scheme outlined above may require modification. It may be advisable to employ several magnetometers, including a stationary magnetometer to monitor diurnal variation. Although this does increase speed of data collection, the amount of labour employed will be substantially increased, as well as the quantity of data to be plotted and interpreted.

The most recently developed magnetometers are able to obtain upper and lower measurements three times faster than conventional single sensor magnetometers. Some of these instruments also store the dual sensor data internally with their associated station coordinates, eliminating the need

for a second individual to record data. Data stored within such machines can be directly transferred electronically to a microcomputer for immediate field processing (Scintrex 1982, personal communication). With this type of instrumentation available it is concievable that a very large amount of magnetic data can be collected, processed and interpreted in a single day. Magnetometers with these capabilities, linked with a computer-based data handling system could potentially assess many hundreds of thousands of square metres of ground in a month, making it a very attractive system for large archaeological projects, or institutions which are responsible for provincial or state cultural resource management programs. These types of magnetometers are a very recent innovation and have not been applied to archaeological site analysis. Thus, they require extensive field testing prior to being seriously considered as alternatives to more conventional equipment.

C. Magnetic Surveying and Archaeological Methods

Although improved instrumentation can potentially simplify the magnetometry technique to a point where most archaeologists will feel confident in employing it in their research, its ultimate value to the profession is dependent upon how intelligently it is applied to specific archaeological problems. It is at the point where

technological presentaion must be shifted to methodological interpretation that magnetic surveying so often fails to benefit archaeological research. This thesis has focussed on attaining the shift from emphasis on geophysical technique to archaeological method. During the course of any magnetic survey on a site, archaeologists must make this shift, even if they are not directly responsible for acquiring and interpreting the data. In fact, archaeologists who employ magnetic surveying techniques must remain cognizant of all parts of the data gathering and interpretation process if they are to ensure that their specific research problems are properly being addressed. Only an individual trained as an archaeologist can successfully carry the results of archaeological magnetic surveys to the point where the data can be used to say something about the people who originally occupied a site. This expertise alone will determine if a magnetic survey is feasible, how it will be carried out, and to what purpose it will serve.

REFERENCES CITED

Aitkin, M.

1958 "Magnetic prospecting I -- the Water Newton survey." ARCHAEOMETRY 1:24-26.

1959a "Magnetic prospecting II." ARCHAEOMETRY 2:32-36.

1959b "Magnetic prospecting IV." ARCHAEOMETRY 2:40-42.

1959c "Test for correlation between dowsing response and magnetic disturbance." ARCHAEOMETRY 2:58-59.

1960 "Magnetic prospecting: the proton gradiometer." ARCHAEOMETRY 3:38-40.

1961a "Measurement of the magnetic anomaly." ARCHAEOMETRY 4:28-30.

1961b "Magnetic location in Britain." ARCHAEOMETRY 4:83-84.

1964 "Archaeomagnetic results: some geophysical implications." ARCHAEOMETRY 7:43-46.

1970a "Magnetic Location." in D. Brothwell and E. Higgs, ed. SCIENCE IN ARCHAEOLOGY, New York: Praeger.

1970b "Magnetic Prospecting." in Berger and Rainer, ed. SCIENTIFIC METHODS IN MEDIEVAL ARCHAEOLOGY, pp. 423-434, Berkeley: University of California Press.

1974 PHYSICS IN ARCHAEOLOGY, 2nd ed., Oxford: Clarenden Press.

Aitken, M., and J. Alldred.

1964 "A simulator-trainer for magnetic prospection." ARCHAEOMETRY 7:28-35.

Aitken, M., and M. Tite.

1962a "Proton magnetometer surveying on some British Hill-Forts." ARCHAEOMETRY 5:126-134.

1962b "A gradient magnetometer using proton free precession." JOURNAL OF SCIENTIFIC INSTRUMENTS 39:625-629.

Aitken, M., G. Webster, and A. Rees.

1958 "Magnetic prospecting." ANTIQUITY 32: 270-271.

Alcock, L.

1972 WAS THIS CAMELOT? EXCAVATIONS AT CADBURY CASTLE; 1966-1970, N.Y.: Stein and Day.

Alldred, J.

1964 "A fluxgate gradiometer for archaeological surveying." ARCHAEOMETRY 7:14-20.

Alldred, J., and M. Aitken.

1966 "A fluxgate gradiometer for archaeological surveying." PROSPEZIONI ARCHAEOLOGICHE 1:53-60.

Aspinall, A., and J. Lynam.

1968 "Induced polarization as a technique for archaeological surveying." PROSPEZIONI ARCHAEOLOGICHE 3:91-93.

Badertscher, P.

1982 ARCHAEOLOGICAL INVESTIGATIONS AT EjMg-2, CHILDS LAKE, DUCK MOUNTAIN PROVINCIAL PARK, MANITOBA. Report in preparation, Winnipeg, Historic Resources Branch, Department of Cultural Affairs and Historic Resources Branch: Manitoba.

Belshe, J.

1961 "Surveys in and around Cambridgeshire." ARCHAEOMETRY 4:73.

Bennet, C., and J. Weymouth

1981 A MAGNETIC SURVEY IN THE PLAZA AREA OF THE SPIRO MOUND SITE. unpublished report submitted to the Oklahoma Tourism and Recreation Department.

Bevan, B.

1975 "A magnetic survey at Les Forges Du Saint-Maurice." MASCA NEWSLETTER 11(2):1.

Bevan, B. and J. Kenyon.

1975 "Ground-penetrating radar for historical archaeology." MASCA NEWSLETTER 11(2):2-7.

Black, G., and R. Johnston.

1962 "A test of magnetometry as an aid to archaeology." AMERICAN ANTIQUITY 28(2):199-205.

Bonnichsen, R., V. Konrad, V. Clay, T. Gibson, and D. Schnurrenberger.

1981 ARCHAEOLOGICAL RESEARCH AT MUNSUNGUN LAKE: 1980 PRELIMINARY TECHNICAL REPORT OF ACTIVITIES. Munsungun Lake Paper, No. 1. Institute for Quaternary Studies, University of Maine at Orono.

Boyer, D., and Pham Van Ngoc.

1971 "A continuous measurement technique for detailed magnetic prospecting. Application to an archaeological site." PROSPEZIONI ARCHAEOLOGICHE 6:43-52.

Breiner, S.

1965 "The rubidium magnetometer in archaeological exploration." SCIENCE 150:185-193.

1972 "Magnetic Exploration of the Olmec Civilization." AMERICAN SCIENTIST 60(5):566-575.

1973 APPLICATIONS MANUAL FOR PORTABLE MAGNETOMETERS. Sunnyvale, California:Geometrics.

Bryan, A., D. Schnurrenberger and R. Gruhn

1980 AN EARLY POSTGLACIAL LITHIC INDUSTRY IN EAST-CENTRAL NEW YORK STATE. Abstracts of the American Quaternary Association Sixth Biennial Meeting: 52.

Carr, C.

1977 "A new role and analytical design for the use of resistivity surveying in archaeology." MID-CONTINENTAL JOURNAL OF ARCHAEOLOGY 2(2):161-93.

Chevrette, L.

1971 "Two geophysical techniuqes applied to archaeology: magnetic location and resistivity surveying." ANTHROPOLOGICAL JOURNAL OF CANADA 9(3):19-27.

Clark, A.

1968 "A square array for resistivity surveying." PROSPEZIONI ARCHAEOLOGICHE 3:111-14.

1976 "Archaeological prospecting: a progress report." JOURNAL OF ARCHAEOLOGICAL SCIENCE 2: 297-314.

Clark, A., and Haddon-Reece.

1972 "An automatic recording system using a Plessey fluxgate gradiometer." PROSPEZIONI ARCHAEOLOGICHE 6:107-113.

Colani, C.

1966 "A new type of locating device. I. The Instrument." ARCHAEOMETRY 9:3-8.

Colani, C., and M. Aitken.

1966a "A new type of locating device. II. Field Trials." ARCHAEOMETRY 9:9-19.

1966b "Utilization of magnetic viscosity effects in soils for archaeological prospection." NATURE 212:1446-7.

Dabrowski, K.

1963 "The application of geophysical methods to archaeological research in Poland." ARCHAEOMETRY 6:83-88.

Darby, E., and E. Davies.

1967 "The analysis and design of two-dimensional filters for two-dimensional data." GEOPHYSICAL PROSPECTING XV:383-406.

Eidt, R.

1973 "A rapid chemical field test for archaeological site surveying." AMERICAN ANTIQUITY 38(2):206-210.

Einstein, S. and D. Goodrow

1981 EXPEDITER II: THE APPLESOFT COMPILER. On-Line Systems. California:Coarsegold.

Fowler, P.

1959 "Magnetic prospecting III, An archaeological note about Madmarston." ARCHAEOMETRY 37-40.

Gibson, T.

1978 AN ARCHAEOLOGICAL AND HISTORICAL ASSESSMENT OF CANNINGTON MANOR HISTORIC PARK manuscript submitted for publication, PASTLOG SERIES, Saskatchewan Museum of Natural History, Saskatchewan Cuture and Youth.

1979 A MAGNETIC SURVEY OF FjPi-29, STRATHCONA SCIENCE PARK, EDMONTON. Report on file, Archaeological Survey of Alberta, Edmonton.

1981 "Revitalizing magnetometer surveying in archaeological site assessment." Paper presented at the Canadian Archaeological Association Conference, Edmonton, April, 1981.

Gramly, R.

1970 "Use of a magnetic balance to detect pits and postmolds." AMERICAN ANTIQUITY 35(2):217-20.

Greig-Smith, P.

1964 QUANTITATIVE PLANT ECOLOGY. Second edition. London:Butterworths.

Hall, E.

1962 "Some notes on the design and manufacture of detector heads for proton magnetometers." ARCHAEOMETRY 5:139-145.

1966 "The use of the proton magnetometer in underwater archaeology." ARCHAEOMETRY 9:32-44.

1970 "Survey techniques in underwater archaeology." PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON A.269:121-124.

Hall, E., and M. Aitken.

1959 "Availability of Magnetic Surveys." ARCHAEOMETRY 2:63.

Hesse, A.

1962 "Geophysical prospecting for archaeology in France." ARCHAEOMETRY 5:123-125.

1966 "The importance of climatologic observations in archaeological prospecting." PROSPEZIONI ARCHAEOLOGICHE 1:11-13

Hickey, C.

1981 ARCHAEOLOGICAL AND HISTORICAL INVESTIGATIONS OF 19th CENTURY COPPER INUIT CULTURE-1st JUNE 1981, 31st MAY 1982. report submitted to Prince of Wales Northern Heritage Museum, Yellowknife.

Howell, M.

1966 "A soil conductivity meter." ARCHAEOMETRY 9:20-23.

Johnston, R.

1961 "Archaeological application of the proton magnetometer in Indiana (U.S.A.)." ARCHAEOMETRY 4:71-72.

1964 PROTON MAGNETOMETRY AND ITS APPLICATION TO ARCHAEOLOGY: AN EVALUATION AT ANGEL SITE Prehistory Research Series Vol. IV (II), Indianapolis:Indiana Historical Society.

Johnston, M., and F. Stacey.

1968 "Magnetic Distrubances Caused by Motor Vehicles and Similar Ferrous Bodies." JOURNAL OF GEOMAGNETISM AND GEOELECTRICITY 20(1):1-6.

Koefoed, O.

1967 "Units in geophysical prospecting." GEOPHYSICAL PROSPECTING XV(1):1-6.

Konrad, V., R. Bonnichsen and V. Clay

1981 "Soil chemical identification of ten thousand years of prehistoric human activity areas at the Munsungun Lake Thoroughfare, Maine." Manuscript submitted for publication, JOURNAL OF FIELD ARCHAEOLOGY.

Le Borgne, E.

1955 "Susceptibilite magnetique anormale du sol superficiel." ANNALES DE GEOPHYSIQUE 11:399-419.

1960 "Influence du feu sur les proprietes magnetiques du sol et sur celles du schiste et du granite." ANNALES DE GEOPHYSIQUE 16:159-194.

Lenius, B., and F. Doolan

1977 "Introducing the proton magnetometer to archaeology in Manitoba." ARCHAE-FACTS 5(2):18-30.

Lerici, C.

1961 "Archaeological surveys with the proton magnetometer in Italy." ARCHAEOMETRY 4:76-82.

Linington, R.

1961 "Physics and archaeological salvage." ARCHAEOLOGY XIV(4):287-92.

1963 "The application of geophysics to archaeology." AMERICAN SCIENTIST 51:48-70.

1964 "The use of simplified anomalies in magnetic surveying." ARCHAEOMETRY 7:3-13.

1966 "An extention to the use of simplified anomalies in magnetic surveying." ARCHAEOMETRY 9:51-60.

1970 "A first use of linear filtering techniques on archaeological prospecting results." PROSPEZIONI ARCHAEOLOGICHE 5:3-54.

1972a "A summary of simple theory applicable to magnetic prospecting in archaeology." PROSPEZIONI ARCHAEOLOGICHE 7:9-60.

1972b "Topographical and terrain effects in magnetic prospecting." PROSPEZIONI ARCHAEOLOGICHE 7:61-84.

1977 "Mossbauer and magnetic susceptibility studies of iron oxides in soils from archaeological sites." ARCHAEOMETRY 19(1):3-14.

Losey, T

1979 FORT GEORGE PROJECT INTERIM REPORT NO. 3: ARCHAEOLOGICAL INVESTIGATIONS, 1979. Report on file, Department of Anthropology, University of Alberta:Edmonton.

Lyons, T., and T. Avery

1977 REMOTE SENSING A HANDBOOK FOR ARCHEOLOGISTS AND CULTURAL RESOURCE MANAGERS Cultural Resources Management Division, National Park Service, U.S. Department of the Interior Washingon, D.C.

MASCA NEWSLETTER

1965a "Instruments: magnetic detection." Applied Science Center for Archaeology, University of Pennsylvania 1(1):1-2.

1965b "Magnetic and resistivity detection at Fort Lennox, Ile-aux-Noix, Quebec." Applied Science Center for Archaeology, University of Pennsylvania 1(1):2-3.

1968 "Archaeological prospecting-instruments and surveys." Applied Science Center for Archaeology, University of Pennsylvania 4(1):1-2.

1969a "Cesium magnetometer survey, San Lorenzo, Mexico." Applied Science Center for Archaeology, University of Pennsylvania 5(1):1.

1969b "Archaeological prospecting." Applied Science Center for Archaeology, University of Pennsylvania 5(2):1-2.

1971 "Cesium magnetometer survey: Kingscote, England." Applied Science Center for Archaeology, University of Pennsylvania 7(2):1-2.

1972 "Cesium magnetometer survey: Gravina Di Puglia, Italy." Applied Science Center for Archaeology, University of Pennsylvania 8(1):3-4.

McLeod, D.

1982 EXCAVATIONS AT THE DELORME HOUSE SITE, 1980-81. Report in preparation. Winnipeg, Historic Resources Branch, Department of Cultural Affairs and Historical Resources: Manitoba.

Morrison, F., R. Clewlow, and R. Heizer.

1970 "MAGNETOMETER SURVEY OF THE LA VENTA PYRAMID AND OTHER PAPERS ON MEXICAN ARCHAEOLOGY." Contributions of the University of California Archaeological Research Facility, no. 8. Berkeley.

Mudie, J.

1962 "A digital differential proton magnetometer." ARCHAEOMETRY 5:135-138.

Mueller, J.

1975 SAMPLING IN ARCHAEOLOGY Tucson:University of Arizona Press.

Nicholas, G., J. Kite and R. Bonnichsen

1981 ARCHAEOLOGICAL SURVEY AND TESTING OF LATE PLEISTOCENE-EARLY HOLOCENE LANDFORMS IN THE DICKEY-LINCOLN SCHOOL RESERVOIR AREA, NORTHERN MAINE. Final Report Institute for Quaternary Studies, University of Maine at Orono.

Parrington, M.

1979 "Geophysical and aerial prospecting techniques at Valley Forge National Historical Park, Pennsylvania." JOURNAL OF FIELD ARCHAEOLOGY 6:193-201.

Peucker, T.

1972 COMPUTER CARTOGRAPHY Commission on College Geography, Association of American Geographers Resource Paper No. 17:Washington, D.C.

Pollock, J.

1980 AN ARCHAEOLOGICAL IMPACT STUDY OF FORT SELKIRK AND FORTY MILE HISTORIC SITES. unpublished report submitted to Yukon Territorial Government:Whitehorse.

Philpot, F.

1972 "An improved fluxgate gradiometer for archaeological surveys." PROSPEZIONI ARCHAEOLOGICHE 7:99-106.

Rainey, F., and E. Ralph.

1966 "Archaeology and its new technology." SCIENCE 153:1481-1491.

Ralph, E.

1964 "Comparison of a proton and a rubidium magnetometer for archaeological prospecting." ARCHAEOMETRY 7:20-27.

Ralph, E., F. Morrison and D. O'Brien.

1968 "Archaeological surveying utilizing a high-sensitivity difference magnetometer." GEOEXPLORATION 6:109-122.

Sampson, R.

1978 SURFACE II GRAPHICS SYSTEM Series on Spatial Analysis No. 1 Lawrence, Kansas Geologcal Survey: Kansas.

Schnurrenberger, D. and T. Gibson

1980 CARIBOU ISLAND PROJECT INTERIM REPORT. report submitted to the Boreal Institute for Northern Studies, University of Alberta:Edmonton.

Scollar, I.

1961 "Magnetic prospecting in the Rhineland." ARCHAEOMETRY 4:74-75.

1962 "Electromagnetic prospecting methods in archaeology." ARCHAEOMETRY 5:146-153.

1963 "A proton precession magnetometer with diurnal variation correction." ELECTRONIC ENGINEERING 35(421):177-179.

1965 "A contribution to magnetic prospecting in archaeology." ARCHAEO-PHYSICA TECHNISCHE UND NATURWISSENSCHAFTLICHE BEITRAGE ZUR FELDARCHAOLOGIE (BONNER JAHRBUCHER) 15:21-92.

1966 "Recent developments in magnetic prospecting in the Rhineland." PROSPEZIONI ARCHAEOLOGICHE 1:43-52.

1968a "Automatic recording of magnetometer data in the field." PROSPEZIONI ARCHAEOLOGICHE 3:105-109.

1968b "A simple direct reading susceptibility bridge." JOURNAL OF SCIENTIFIC INSTRUMENTS (Journal of Physics E) series 2, 1:781-782.

1968c "A program package for the interpretation of magnetometer data." PROSPEZIONI ARCHAEOLOGICHE 3:9-18.

1969 "Some techniques for the evaluation of archaeological magnetometer surveys." WORLD ARCHAEOLOGY 1:77-89.

1070a "Magnetic methods of archaeological prospecting - advances in instrumentation and evaluation techniques." PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON. A. 269:109-119.

1970b "Fourier transform methods for the evaluation of magnetic maps." PROSPEZIONI ARCHAEOLOGICHE 5:9-41.

1970c "A wide range, differential proton magnetometer with direct readout in gammas." PROSPEZIONI ARCHAEOLOGICHE 5:59-66.

1972 "Magnetic mapping of buried archaeological sites." ENDEAVOR 31:34-40.

1974 "Interactive processing of geophysical data from archaeological sites." COMPUTER APPLICATIONS IN ARCHAEOLOGY University of Birmingham.

Scollar, I., and F. Kruckberg.

1966 "Computer treatment of magnetic measurements from archaeological sites." ARCHAEOMETRY 9:61-71.

Stanley, J., and R. Green.

1976 "Ultra-rapid Magnetic surveying in archaeology." GEOEXPLORATION 14:51-56.

Steponaitis, V. and J. Brain.

1976 "A portable differential proton magnetometer." JOURNAL OF FIELD ARCHAEOLOGY 3:455-63.

Strangway, D.

1970 HISTORY OF THE EARTH'S MAGNETIC FIELD N.Y.:McGraw-Hill.

Tite, M.

1961 "Alternative instruments for magnetic surveying." ARCHAEOMETRY 4:85-90.

1966 "Magnetic prospecting near to the geomagnetic equator." ARCHAEOMETRY 9:24-31.

1972a "The influence of geology on the magnetic susceptibility of soils on archaeological sites." ARCHAEOMETRY 14(2):229-236.

1972b METHODS OF PHYSICAL EXAMINATION IN ARCHAEOLOGY, N.Y.:Seminar Press.

Tite, M., and C. Mullins.

1969 "Electromagnetic prospecting: a preliminary investigation." PROSPEZIONI ARCHAEOLOGICHE 4:95-102.

1970 "Electromagnetic prospecting on archaeological sites using a soil conductivity meter." ARCHAEOMETRY 12(1):97-104.

1971 "Enhancement of the magnetic susceptibility of soils on archaeological sites." ARCHAEOMETRY 13(2):209-219.

Vickers, R., and L. Dolphin.

1975 "A communication on an archaeological radar experiment at Chaco Canyon, New Mexixo." MASCA NEWSLETTER 11(1):6-8

Wilcock, J.

1968 "A comparison of computer graphic techniques for the automatic reduction of archaeomagnetic field observations." PROSPEZIONI ARCHAEOLOGICHE 3:87-90.

1970 "Some developments in the portrayal of magnetic anomalies by digital incremental plotter." PROSPEZIONI ARCHAEOLOGICHE 5:55-58.

Weymouth, J.

1976 A MAGNETIC SURVEY OF THE WALTH BAY SITE. Lincoln:Midwest Archaeological Center.

1979 A MAGNETIC SURVEY OF THE BIG HIDATSA SITE (32 ME 12), KNIFE RIVER INDIAN VILLAGES NATIONAL HISTORIC SITE. Unpublished report submitted to U.S. National Park Service.

1981a A PROTON MAGNETOMETER SEARCH FOR THE ROCK CREEK STATION ON THE OREGON TRAIL, NEBRASKA unpublished report submitted to the Nebraska State Historical Society and the Nebraska Game and Parks Commission.

1981b MAGNETIC SURVEYS OF THE EDWARDS I (34Bk2) AND THE TAYLOR (34Gr8) SITES IN WESTERN OKLAHOMA unpublished report submitted to the Oklahoma Archaeological Survey, University of Oklahoma.

Weymouth, J., and R. Nickel.

1977 "A magnetometer survey of the Knife River Indian Villages." PLAINS ANTHROPOLOGIST 22-78 Pt.2 (Memoir 13):104-113.

Zurflueh, E.

1967 "Applications of two-dimensional linear wavelength filtering." GEOPHYSICS 32(6):1015-1035.

APPENDIX A

MAGNETIC DATA PROCESSING PACKAGE (MDPP)

The following tables present a summary of the purposes and capabilities of the programs written to aid in the interpretation of magnetic data from archaeological sites. All programs are designed as stand-alone procedures in that they are executed singly as they are required by the user. No program must be executed to call another. However, most require that data be input from a specially formatted disc file created by the DATA* program. The hardware requirements to run them are as follows:

48K Apple II+ computer with Applesoft in ROM

Disc II with DOS 3.3

Silentype thermal printer

If another type of printer is used, the PLOT* program will probably not be able to provide a hard copy of plots that are drawn; they will have to be saved on disc and then manually transferred to hard copy. The STATS* program may also produce unpredictable results.

Currently, all programs in this package can accomodate data from a 20 unit square grid at intervals of 1 unit.

Thus, 441 stations can be accomodated by each program at two sensor positions. This means that that a maximum of 882 magnetic measurements can be computed at one time. Intervals greater or less than one unit may be specified, but this does not change the maximum number of stations that can be computed. In the examples below, all execution times are based on data from a 20 X 20 unit grid gathered at a 1 unit interval, and the entire grid, rather than portions of it, was assessed.

Most programs that were written by the author have been compiled into machine code using a commercially available compiler software package called EXPEDITER II (Einstein and Goodrow 1981), marketed by On-Line Systems, Coarsegold, Ca. The primary purpose of the compilation is to speed up execution time.

PROGRAM	-	DATA*
LANGUAGE	-	Applesoft BASIC
PURPOSE	-	Create and edit data files for other MDPP programs
INPUT	-	Keyboard, disc
OUTPUT	-	Screen, printer, disc
EXECUTION	-	Loading data = 20 seconds; Keyboard entry = 30 minutes
PROPRIETOR	-	T.H. Gibson

PROGRAM	-	STATS*
LANGUAGE	-	Compiled Applesoft BASIC
PURPOSE	-	Statistical summary of partial or whole data file
INPUT	-	Disc
OUTPUT	-	Screen, printer, disc
EXECUTION	-	Loading data = 20 seconds; Calculating and printing = 200 seconds
PROPRIETOR	-	T.H. Gibson

PROGRAM	-	PLOT*
LANGUAGE	-	Compiled Applesoft BASIC
PURPOSE	-	Post values and/or contour all or part of a data file
INPUT	-	Disc
OUTPUT	-	Screen, printer, disc
EXECUTION	-	Loading = 20 seconds; Plotting = 285 seconds (21 contours)
PROPRIETOR	-	T.H. Gibson

PROGRAM - FILT*

LANGUAGE - Compiled Applesoft BASIC

PURPOSE - Selectively filter all or part of a data file

INPUT - Disc

OUTPUT - Screen, printer, disc

EXECUTION - Loading = 20 seconds; Filtering = 10 seconds

PROPRIETOR- T.H. Gibson

Recommended Ancillary Software

PROGRAM - APPLE PLOT

LANGUAGE - Applesoft BASIC

PURPOSE - Create histograms and profiles of magnetic profile data

INPUT - Keyboard, disc

OUTPUT - Screen, printer, disc

EXECUTION - Depends on profile length (maximum 100 points = 20-40 seconds)

PROPRIETOR- Apple Computer Inc., Cupertino, California

Copies of the software in which the author is proprietor can be obtained on disc (APPLE DOS 3.3) from the Norman Zierhuit Library, Department of Anthropology, University of Alberta. With the exception of the DATA* program, only compiled code is available. For program documentation and access to source code, contact the author, care of the Department of Anthropology, University of Alberta, Edmonton, Alberta.

APPENDIX B.

SUMMARY OF SITES PROVIDING DATA FOR THIS THESIS

Map	Locality	Type	Prov./State	Reference
A	Cannington Manor	hist	S. Eastern Saskatchewan	Gibson 1978
B	Strathcona	preh	Central Alberta	Gibson 1979, Pollock 1980
C	Fort George	hist	E. Central Alberta	Losey 1979
D	Caribou Island	preh	E. Central Alberta	Schnurrenberger and Gibson 1980
E	Timlin	preh	N. Central New York	Bryan et al 1980
F	Munsungun Lake	preh	Northern Maine	Bonnichsen et al 1981
G	Fort Selkirk	hist	S. Yukon Territory	Pollock 1980
H	Forty Mile	hist	C. Yukon Territory	Pollock 1980
I	Dickey-Lincoln	preh	Northern Maine	Nicholas et al 1981
J	Souris Mouth	hist	S. Western Manitoba	Hamilton 1982
K	Delorme	hist	Southern Manitoba	McLeod 1981
L	Child's Lake	preh	W. Central Manitoba	Badertscher 1982
M	Mercy Bay	hist	N. Banks Island, NWT.	Hickey 1981

See the accompanying map (figure B.1) for the general location of each site.

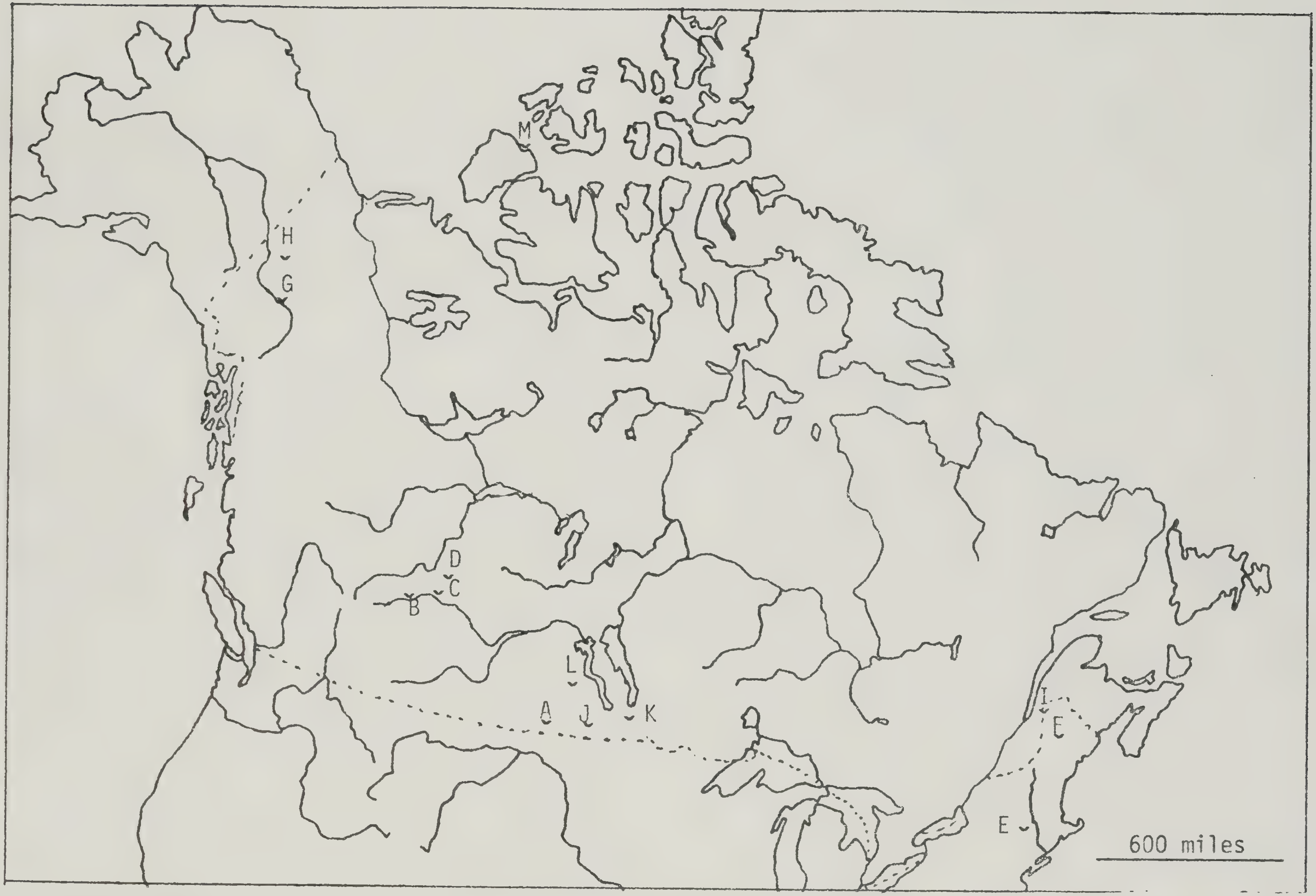


Figure B.1. Map of northern North America showing location of sites investigated for this study.